DEPARTMENT OF THE INTERIOR, CANADA

Hon. Thomas G. Murphy,
Minister

H. H. Rowatt,
Deputy Minister

TOPOGRAPHICAL SURVEY BULLETIN No. 62

THE USE OF AERIAL PHOTOGRAPHS FOR MAPPING

OTTAWA
F. A. ACLAND
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1932

Price, 25 cents

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FOREWORD

The various sections of this pamphlet have been prepared by the officers of the Topographical Survey who are responsible for the practical execution of the work and who have been associated with the development of the methods now employed. The production of a good map by the use of aerial photography depends upon a number of considerations, not the least of which is the obtaining of good photographs. While the burden of this publication is to explain the methods of plotting the maps from the photographs, the work could not have been developed by the Topographical Survey as it has been, were it not for the fine co-operation which has been extended by the Royal Canadian Air Force of the Department of National Defence. This latter organization has done, and done well, a very notable work in taking and supplying, with but a few minor exceptions, the photographs that have been used.

F. H. PETERS,
Surveyor General

OTTAWA, January, 1932.

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The Use of Aerial Photographs for Mapping

INTRODUCTION

The mapping of half a continent is a tremendous undertaking requiring the utilization of all the resources of the science of surveying and mapping. In Canada, the problem is accentuated on account of the vast territory rich in natural resources which is waiting to be accurately mapped as a prime requisite to its orderly and economical development and on account of the tremendous expansion into new fields of discovery in minerals, and the like, which is presently taking place. At the same time, the small population makes it difficult to provide sufficient funds for the prosecution of the mapping work.

This situation, affecting the mapping work in common with many other government activities, has made it necessary to closely study not only the technical aspects of the work, but also the question of costs. The maximum of financial economy must accordingly be aimed at in the methods adopted for mapping the different types of country which have required attention from time to time as the country's expansion has progressed.

Dealing with conditions in the past, the late Dr. E. Deville, Surveyor General of Canada, in writing the introduction to his well-known book on *Photographic Surveying*, in 1889, expressed himself as follows:—

> "When the surveys of Dominion Lands were extended to the Rocky Mountains region, it was found that the methods hitherto employed were inadequate. The operations in the prairies consisted merely in defining the boundaries of the townships and sections; these lines form a network over the land by means of which the topographical features, always scarce in the prairies, are sufficiently well determined for general purposes.
>
> "In passing to the mountains, the conditions are entirely different; the topographical features are well marked and numerous, and the survey of the section lines is always difficult, often impossible and in most cases useless. The proper administration of the country required a tolerably accurate map; means had to be found of executing it rapidly and at a moderate cost.
>
> "The ordinary methods of topographical surveying were too slow and expensive for the purpose; rapid surveys based on a triangulation and on sketches were tried and proved ineffectual, then photography was resorted to and the results have been all that could be desired.
>
> "The application of photography to surveying is as old as the art itself. Arago, in presenting Daguerre's discovery (in 1839) pointed out its application to surveying, but it was not until twenty-five years later that Laussedat gave in the 'Memorial de l'Officier du Genie' a full exposition of the method. His work was so complete that little has been added to it since."

At the present time, accurate mapping is required in those northern areas where so much pioneer work is going on in prospecting and the development of minerals, water powers, forest resources, and the like. These areas are generally heavily wooded and exhibit a great mass of topography in the minor or disconnected water features. There are no roads or other ways of travel or transport on the ground save the few routes provided by the main or through waterways.

Such areas cannot, on account of the restricted vision due to the heavy forest cover, be accurately and economically mapped in detail by any known method of ground survey. As in going from the prairie to the mountains, some new method had to be developed. The result may best be described by adapting the words of Deville—photography, this time from the air, was resorted to and the results have been all that could be desired.

Mapping from the ground by photographic methods, as instituted by the late Dr. Deville, has been carried out more extensively in the Rocky Mountains

of Canada than anywhere else in the world. The method employed in the mountains, well described by Bridgland in Bulletin No. 56, *Photographic Surveying*, of the Topographical Survey, is based upon triangulation control, the detail being obtained by photographs taken in a vertical plane from fixed camera stations by the use of an accurately levelled surveying camera, the true orientation of each photograph being obtained by means of an auxiliary transit.

With the advent of the aeroplane, a radical change has been introduced, in that the photographs are taken from a moving platform, the position of which is not directly known, and can only be determined by very laborious calculations involving certain ground data. In addition, the camera can neither be accurately levelled nor can its true orientation be independently obtained. However, in spite of this, when sufficient ground control is available, any aerial photograph taken with a camera of known focal length may be utilized as a mapping photograph. The problem has been to develop methods most economical and advantageous for the purposes in hand.

Just as in photo-topographic methods of mapping, mapping from the air by photographic methods has also been carried out more extensively in Canada than in any other country of the world. In the following sections an endeavour has been made to explain the methods which have been developed and adopted by the Topographical Survey to meet the conditions which exist in Canada and to which reference has already been briefly made.

In the use of aerial photographs for mapping, control from ground surveys is, of course, still required, although the connection between the photographs and the control is established in a different manner than in the photo-topographic work carried on in the mountains. In the latter case, the mapping detail is controlled directly by setting up the surveying camera on the control points and taking photographs from them. With regard to the photographs taken from the air, however, the process is in a sense reversed and the connection between the control and the photograph is obtained by photographing the control points so that they may appear as recognizable points on the photographs, in which case they may be made to control the detail by the application of various methods of plotting.

The aerial photographs permit of a great deal of flexibility in allowing the ground control to be placed where the greatest economy can be effected. As in all mapping work, however, the consistent accuracy of the map depends greatly upon the accuracy and amount of the control. These points will be more completely brought out in the section on ground control which appears later in this bulletin. Where visible cadastral survey lines appear on the aerial photographs the compiling of a map from them lends itself to that most desirable feature of maintaining a very intimate connection between the map and such surveys on the ground.

AERIAL SURVEY CAMERA

In photo-topographic surveying as employed, for instance, in the Rocky Mountain region of Canada, commanding positions giving an unobstructed view of the area to be mapped are made use of from which ground photographs can be taken. When taking the photographs the ground surveyor carefully levels his camera and also makes the precise measurements for determining its position and orientation as required later in the office for plotting purposes. Exposures of relatively long duration can thus be carried out without difficulty. In photographing from an aircraft, however, the conditions are quite different.

For one thing, the viewpoints afforded by the aircraft are vastly superior to those available on land so far as the extent of territory covered is concerned. In vertical aerial photography the camera axis is maintained as nearly as possible in a vertical position; while in oblique aerial photography it is maintained at a definite depression below the apparent horizon. These orientations,

however, cannot be made with anything like the precision prevailing in ground work. The limited time available between exposures demands speedy action with the camera placed in rather cramped quarters, while varying accelerations of the aircraft affect the use of level bubbles in fixing the vertical. The engine vibration is considerable and it, together with the high speed of the aircraft, tends to make exposures of long duration impracticable.

These different conditions experienced in obtaining and mapping from aerial photographs as compared with ground photographs, are largely responsible for the development of the present types of aerial survey cameras. They have, however, by no means reached perfection and it may be considered that in the future they will be subject to further modification.

Camera Equipment in Use.—The cameras now in use in obtaining aerial photographs for the mapping purposes of the Topographical Survey are of the single lens type, and are referred to by the makers, respectively, as the K_3 model, and the F_3 design, the latter being a modification of the former. In the F_3 camera the focal plane contact glass plate is contained within the camera body instead of in the bottom of each magazine, as is the case in the K_3 model. In other respects the cameras are alike.

The K_3 Aerial Camera is entirely automatic and is so designed that the interval between exposures may be varied from 5 or 6 seconds to over 1 minute. The shutter is of the between-the-lens type, giving nominal exposures of 1/50, 1/100 and 1/150 seconds, and is carried in the aluminium cone which attaches to the camera body. Lenses of focal length approximately $8\frac{1}{4}$ inches, and of other focal lengths such as 10 inches, 12 inches and 20 inches, are available, housed in their respective cones and calibrated for the particular camera with which they are used. The maximum stop opening of these lenses varies from f/4 to f/6·8, but the former is preferable for all aerial survey lenses.

Camera Magazine.—The camera magazine uses film $9\frac{1}{2}$ inches wide and 75 feet long, which is sufficient for 115 exposures, each approximately $7'' \times 9\frac{1}{4}''$. The magazine is equipped with an indicating dial which shows the number of pictures taken, and also with a spacing device for automatically controlling the spacing of the film. The magazine of the K_3 Model camera contains also the pressure plate, the contact glass plate, and the light slide. At the time of actual exposure the film is held against the contact glass by means of the pressure plate. When the exposure has been made and the film is to be rewound, the pressure plate automatically releases and allows the film to pass on rollers between the pressure plate and contact glass without any part of the film touching the latter two units.

The camera is motor driven, power being provided by a storage battery. It may be loaded during flight; the magazine with the exposed films may be removed and another containing unexposed film quickly substituted. The timing instrument for automatically operating the shutter at any predetermined interval is called the Intervalometer.

In taking vertical aerial photographs, when it is set at the interval required to give the desired overlap between photographs, the motor will trip the shutter, count the exposure, remove the pressure of the film pressure plate, wind an unexposed portion of the film into position, replace the film pressure plate so that the film is held in close contact with the glass focal plane plate, and set the shutter ready for the next exposure.

By the trunnion arms provided on the sides of the cone the camera is suspended and levelled in the gimbal mount which permits its rotation about a vertical axis to compensate for crab* in vertical photography. As a means for determining the correct interval when successive and overlapping vertical exposures are being made, a view-finder is provided. The view-finder is mounted

*The angle of crab is the angle between the projection on the ground plane of the longitudinal axis of the plane when in flight and the actual course or track followed.

in a ball and socket joint and is supplied with a ground glass on which are engraved two lines one-half inch apart representing drift lines and two lines at right angles thereto. The separation of the latter two lines is such that the time taken by a chosen image point in passing from one line to the other represents the interval between consecutive camera exposures to give a 60 per cent overlap in the direction of flight with the particular lens employed.

Aerial Survey Camera

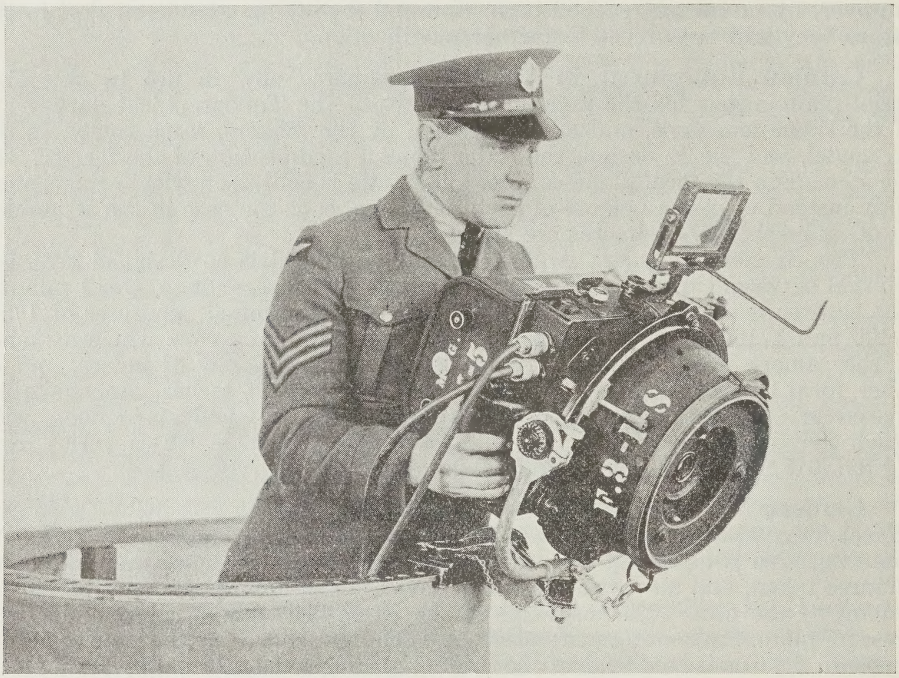


Fig. 1

The aerial survey camera shown above is mounted in the front cockpit of the plane ready for taking oblique aerial photographs. It is supported by means of an encircling band attached to the ends of a forked standard. The encircling band fits around the base of a cone containing the lens elements; the standard can be moved along the circular track arranged in the front cockpit, so as to allow the camera to be swung through a horizontal arc of about 200 degrees. The oblique sight is clamped in position to the camera trunnion and consists of a negative lens rigidly attached to a sighting arm which can be rotated through a limited range in a vertical plane and clamped at the required depression angle. In taking oblique photographs, the depression angle is first set off on the sight and thereafter the camera axis is held at the required depression by directing the sight to the apparent horizon.

In taking oblique aerial photographs of the mapping type (see Fig. 1) the camera is suspended by a rubber collar which encircles the cone and is attached to a Y-shaped mount which is held vertical and free to travel along a semi-circular track on the front cockpit of the aircraft. A special oblique camera sight is attached and clamped in correct adjustment to the camera trunnion and set to read the previously determined angle of the camera depression below the apparent horizon. Thereafter the camera is maintained in position by directing the sighting device to the apparent horizon.

Supersensitized panchromatic film is used on all aerial photography carried out with the available equipment described above. Panchromatic emulsion is sensitive to all colours, but is excessively sensitive to blue, and hence it is necessary to use a yellow filter in photographing from the air, to overcome the fine

blue haze, and to obtain "contrasty" pictures. A yellow filter holds back the blue rays so that other colour rays may have time to make an impression on the panchromatic emulsion. The yellow filters at present employed are: (a) the gelatine type which are inserted between the lens components, and (b) a type in which the yellow filter pigment is contained between two parallel optical flats which are fitted to a cylindrical sleeve and by which the outer lens mount is capped. The latter facilitates the change of filter in the air and as all objects photographed are at an infinite distance, no distortion is introduced by the filter.

Lenses for Aerial Survey.—For survey purposes an aerial photograph should be in correct perspective, that is, angle true, with a field of view of wide extent and free from distortion. A knowledge of the location of the perspective centre is required and this information is obtained in the calibration of the camera. This is the point on the photograph from which any two image points of the photograph will subtend the same angle as their corresponding object points subtend in Nature. The print used in plotting is made by contact from the negative obtained in the camera focal plane. The perspective centre of the camera negative is situated on the optical axis of the camera lens at or near the camera lens rear node. Its relative position is referenced by dropping a perpendicular to the camera focal plane, by marking the principal point or foot of this perpendicular either directly or indirectly and by determining the principal distance or length of this perpendicular.

In aerial survey cameras the focal register is set for objects at infinity. Accordingly, the principal distance corresponds closely to the focal length of the lens, but its actual value is obtained by calibration measurements. Where a focal plane glass plate against which the film is pressed during the exposure instant is provided, as in the K_3 camera, the position of the principal point on each negative is most easily established by etching on it a cross in correct position. Once this has been done it is essential that the construction of the camera ensures that it will not be disturbed by rough handling, vibration or by looseness in fittings. For this reason the focal plane glass plate is preferably placed in the camera body as in the F_3 camera instead of in the magazine as in the K_3 camera.

Covering Power of Lenses.—For economy in mapping, it is important that the field of view or covering power of the lens employed be as large as possible. Where the exposure area of a camera is fixed, such as in the K_3 camera, then a lens should preferably be employed with a focal length as short as will wholly cover the plate, provided its speed is satisfactory. The covering power is usually expressed as the ratio of the diagonal of the exposure area to the focal length of the lens. In the K_3 camera the covering power of an 8″ lens that will effectively cover the 7″ x 9″ exposure area is approximately 1·4. Lenses of this covering power and with a speed of f/4 are now available. Survey lenses of greater covering power than 1·4 are available but their speed is insufficient for aerial work except when used with special emulsions of abnormal speeds.

Speed of Lenses.—The speed or light-gathering power of a lens is proportional to the square of its numerical aperture. Thus the speed of a lens whose diameter of maximum stop opening is one-quarter times its focal length, usually expressed as f/4, is 2·9 times as great as one whose maximum working aperture is f/6·8. With good lenses of speed f/4 good negatives can be obtained under most adverse circumstances, so far as the nature of the lighting and the real or apparent movement of the object photographed is concerned. The necessity for employing light filters to overcome the disturbing effects of aerial haze as used with panchromatic emulsion tends to increase the duration of the exposure necessary to obtain a negative of proper density. Emulsions can be speeded up by hypersensitization, but the makers do not recommend carrying hypersensitization very far. In the northern latitudes of Canada it is

desired to take full advantage of all suitable weather and to carry on aerial photography under light conditions which may not be considered ideal. In these matters the use of high speed lenses such as f/4 combined with hypersensitization of the emulsions employed greatly assists in the solution of the problem.

Sharpness of Negatives.—In negatives which may subsequently be enlarged the diameter of the circle of confusion of a point image should not exceed 0·005 inches. In a lens working at aperture f/4, such as those recommended for aerial photography, this limit would be reached if the focal register were displaced 0·02 inches laterally from the position which gives critically sharp definition for objects at infinity distance. Also, in critically sharp negatives, the travel of an image point during the exposure instant should not exceed 0·005 inches. In an aircraft travelling at a speed of 70 miles an hour and photographing vertically from an altitude of 1,000 feet, with a lens of 8·2″ focal length, this limit is reached in an exposure of duration 1/160 seconds. When photographing from higher altitudes the duration of exposure may be increased proportionately in so far as the effect of aircraft speed is concerned. Provision is usually made in the camera mounting for dampening the engine vibrations which would otherwise be transmitted to the camera. These vibrations are of such magnitude and frequency as to otherwise cause, during the exposure instant, considerable angular motion to the camera axis and would result in lack of sharpness in the negative obtained. The vibrations cannot be entirely eliminated but a fast lens serves to shorten the duration of the exposure and in that way it makes the negative less likely to be affected by this cause.

Distortions.—The lesser weight of celluloid film compared to glass and its freedom from breakage makes it attractive as a base for emulsion in aerial photography. The celluloid base, however, is not very stable. The shrinkage of film negatives from their predevelopment dimensions has been found in the case of film base of thickness 0·0065 inches to have a mean value of about 0·57 per cent. In the graphical method of plotting from oblique aerial photographs described later on, this is taken into account. In plotting from vertical aerial photographs, the distortion may be considered radial from the principal point, and accordingly does not affect the precision of the work. Manufacturers have recently placed on the market a film in which the shrinkage factor is much less than the above.

Several methods are employed to ensure the film being maintained flat and in the camera focal plane during the instant of exposure. The usual method is to insert in the camera a glass plate, whose opposite faces are optically flat and parallel, and adjust the position of the lens relative to it so that the side of the glass plate away from the lens actually marks the focal register of the camera for objects at infinity distance. Its introduction causes distortions, but they are not of sufficient magnitude to affect graphical plotting of the photographs.

Camera Calibration.—The method at present employed for determining the position of the principal point of the K_3 camera is known as the Grove-Hill method. The camera is set up as indicated in Fig. 2 with its axis in a vertical position, lens downward over a dish of mercury. The focal plane is levelled by means of a sensitive level placed on the focal plane glass plate against which the film is pressed at the exposure instant. A small piece of white paper cut at a sharp angle is then placed on this glass plate and moved until the image of its apex formed by passages through the lens and reflection from the mercury coincides with the object, that is, the apex of the paper. A magnifier is employed to obtain precision in this coincidence and when image and object thus coincide they indicate the true position of the principal point. The paper is then secured

in this position to the focal plane glass plate and the principal point location is etched on the glass plate, the etched cross being later filled in with black engraver's pencil so as to be clearly visible in each negative.

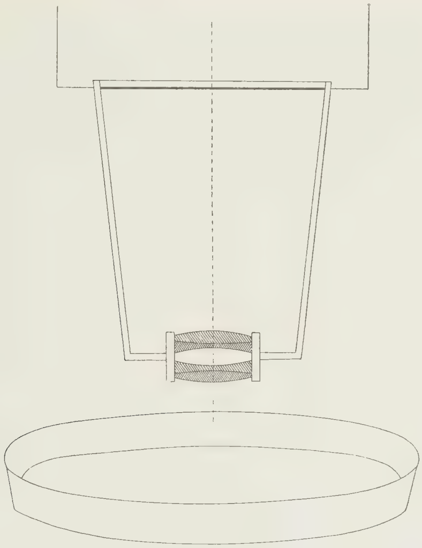


Fig. 2

The method employed for the determination of the principal distance is as follows. The camera is set up on a pier where it can be carefully levelled and directed so that well-defined distant features at the same level as the camera will appear in the camera field of view. The camera is then levelled fore and aft and transversely, making sure that the transverse or horizontal axis of the camera is accurately level. An exposure is then made. In the resulting negative, three well-marked features clearly visible and appearing on the horizontal axis of the camera are selected so that two points are near the extremities of the camera field and the third is near the middle. By means of a theodolite set up in the position occupied by the camera lens, the horizontal angles between the three points chosen from the photograph are accurately measured by sighting at the objects themselves. The distances between the three image points are measured carefully on the negative as well as the length of the marginal rectangle which appears on the focal plane glass plate, and thus is recorded on the negative. The factor determined by comparing the length of the marginal rectangle as measured on the glass plate and as measured on the film, is applied as a multiplier to the measured distances to give their predevelopment dimensions. From the two angles measured on the ground and the two corrected distances measured on the negative, the principal distance is determined thus, referring to Fig. 3 the objects sighted are marked 1, 2 and 3; 1 and 2 subtending the angle A, and 2 and 3 subtending the angle B at the point of observation. If the distance measured on the negative between image point 1 and image point 2 be designated by a, and the distance between image points 2 and 3 by b, then the principal distance f is given by the equation:—

$$f = \frac{a\, b\, (a + b)}{a^2 \cot A + b^2 \cot B - (a + b)^2 \cot (A + B)}$$

A reading is taken with a collimator through the camera lens on a scale placed in the camera focal plane to obtain an approximate value of the principal distance to serve as a rough check on the work.

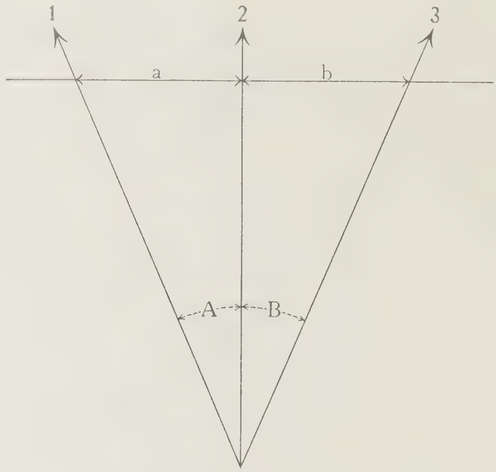


Fig. 3

THEORY OF PLOTTING FROM OBLIQUE AERIAL PHOTOGRAPHS

An oblique aerial mapping photograph as used by the Topographical Survey is one taken by a previously calibrated fixed-focus aerial survey camera with the apparent horizon included in its field of view. The inclusion of the apparent horizon line serves with the known camera constants obtained by calibration, to determine the orientation of the photograph relative to the horizontal plane containing the lens. If, in addition, two suitably situated ground control features are included in the field of view, the altitude of the lens at the time of exposure above such ground control features, together with the direction of camera pointing, can also be determined.

With the photograph thus fixed in space, the location in the ground plane of any object is determined by joining the image point to the perspective centre of the photograph and producing this ray to intersect the ground plane. This assumption indicates that the method is applicable only to those areas where for the purposes of the map the ground may be considered a level plane.

The Use of Perspective Grids.—The determination of the camera air position and of the drawing of the rays to intersection as above referred to, are in practice mechanically effected by the use of perspective grids in the construction of which the particular orientation and altitude of air position of the photograph have been considered. These perspective grids representing a system of squares which are made photographically on transparent glass plates, are mechanically superimposed in correct position on the photograph to be plotted. The objects are then plotted by noting their location in the particular square and marking this position in the corresponding square of the compilation sheet. (See Figs. 4 and 5.) These operations are described in more detail in a publication of the Topographical Survey entitled "A Graphical Method of Plotting Oblique Aerial Photographs."

The way in which these grids have been evolved will be further considered.

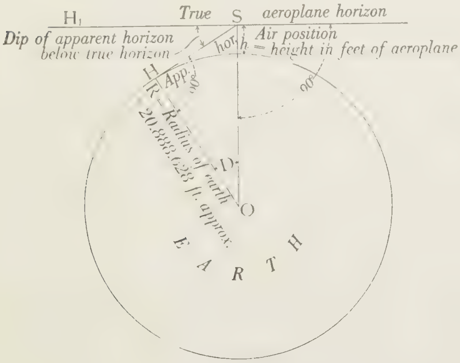
In sextant observations at sea, made by the determination of altitudes of celestial objects, the apparent horizon serves a definite purpose. This purpose relates to the locating of the vertical plane in which the altitude angle must be

measured containing the observer's eye and the celestial object as well as to the position in this plane, of a horizontal line through the point of observation. The latter may be obtained when the height above sea level of the observer's eye is known. The dip of the apparent horizon below the true horizon for use

FIG. 4.—Oblique Aerial Mapping Photograph with Plotting Grid Superimposed. For plot developed from this photograph see Fig. 5.

in such observations is determined from the expression: Dip = $59\sqrt{h}$* (1) where Dip = the dip angle expressed in seconds of arc, and h = the distance above sea level of the observer's eye expressed in feet.

*The derivation of this formula is given in Fig. 1 of the bulletin of the Topographical Survey "A Graphical Method of Plotting Oblique Aerial Photographs." Briefly it is as follows:—



$$\text{Tan Dip} = \frac{SH}{OH} = \frac{\sqrt{SO^2 - OH^2}}{OH} = \sqrt{\frac{2h}{R} + \frac{h^2}{R^2}}$$

As $\frac{h^2}{R^2}$ is very small, it may be neglected without appreciable error

$$\therefore \text{Tan Dip} = \sqrt{\frac{2h}{R}} = \sqrt{\frac{h}{10444314}}$$

Also, Dip being a small angle, we may write
Tan Dip = Dip″ tan 1″

$$\therefore \text{Dip}'' \tan 1'' = \sqrt{\frac{h}{10444314}}$$

$$\therefore \text{Dip} = 206265\sqrt{\frac{h}{10444314}} = 63''{\cdot}82\sqrt{h}$$

To correct for refraction multiply value of Dip above by 0·9216

Dip in seconds = $58{\cdot}82\sqrt{h} = 59\sqrt{h}$

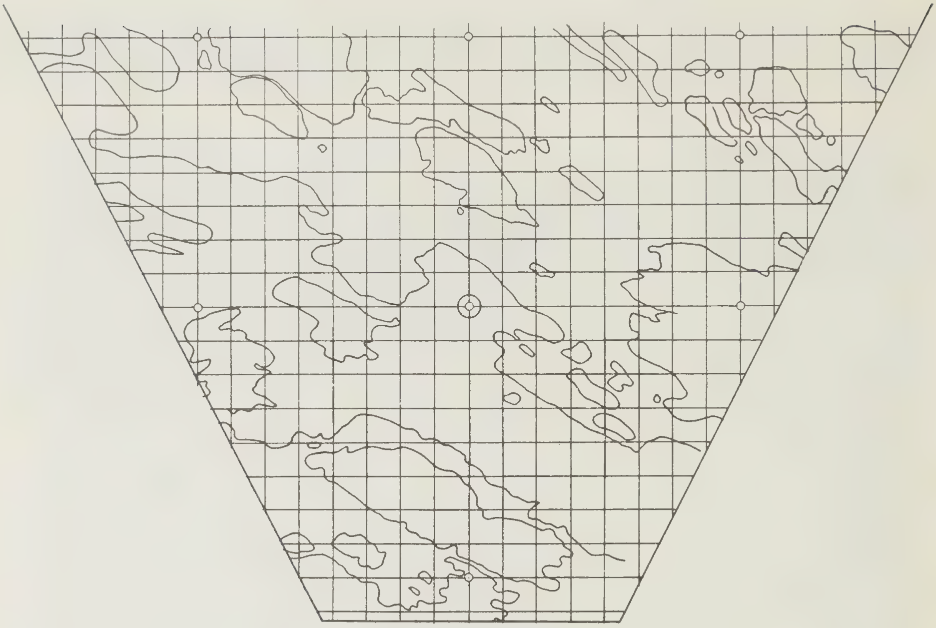


Fig. 5.—Plot Developed from Oblique Aerial Mapping Photograph shown in Fig. 4.

Perspective Elements of the Oblique Photograph.—In taking oblique aerial mapping photographs, the apparent land or sea horizon is included in the field of view for a similar purpose. This purpose is to fix the relation of the photograph to the vertical plane containing the camera axis at the time of exposure, as well as to the horizontal plane passing through the rear node of the camera lens or perspective centre of the photograph, so that the directions from such perspective centre to image points in the photograph will be in agreement with the true directions from such point to the objects themselves. In other words, this determines the orientation of the photograph in space.

By the use of a special camera sight, the apparent horizon line is made to occupy a position parallel to and as close as is practical to the upper limit of the photograph. In this way the amount of dead ground—sky and unplottable area near the apparent horizon—is kept as small as possible. The record of the apparent horizon on a mapping oblique photograph taken over a level area departs slightly from a straight line. The wider the angle of the camera the greater becomes the departure. In the case of a 7″ x 9″ oblique mapping view taken with a lens of 8″ focal length, this curvature amounts to a few one-hundredths of an inch.

The apparent horizon line itself consists of a hyperbolic curve obtained as a section, by the plane of the photograph, of the right cone formed by the apparent horizon with its apex at the lens centre, the depression of its generating line below the true horizon being obtained from the dip expression given by equation (1). The chord of the portion of the apparent horizon line intercepted by the limits of the photograph may, without sensible error, be assumed to be parallel to the true horizon line.

As indicated in the previous section, the position of the principal point of the photograph, the foot of the normal from the rear node of the camera lens, or perspective centre, to the photo plane, is shown on each view marked by a small cross. This cross is etched on the focal plane glass plate at the principal point, at the time when the camera is calibrated and thus appears on each

negative and the prints therefrom. A normal drawn on the photograph from the principal point to the chord of the apparent horizon will thus define the intersection with the photo plane of the vertical plane containing the camera axis, and this normal is usually called the principal line of the photograph.

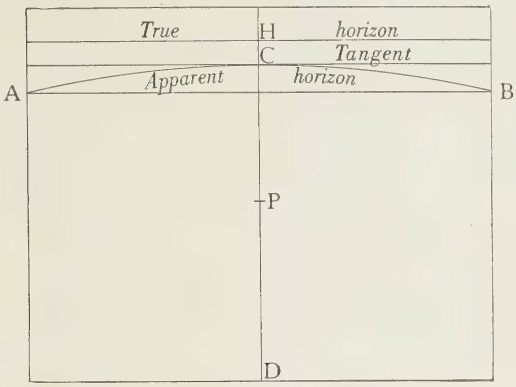


Fig. 6

Thus, in Fig. 6, which represents an oblique aerial mapping photograph,

P is the principal point.
ACB is the apparent horizon line.

A normal from *P* to *AB* meets the apparent horizon line in *C*. *PC* represents the principal line of the photograph, and the tangent to the apparent horizon at *C* is parallel to the chord *AB* and also parallel to the true horizon line formed by the intersection of the photo plane with the horizontal plane containing the perspective centre, which cuts *PC* produced in *H*. The distance *CH* from the apparent horizon must be determined, and the manner in which this is done is as follows:—

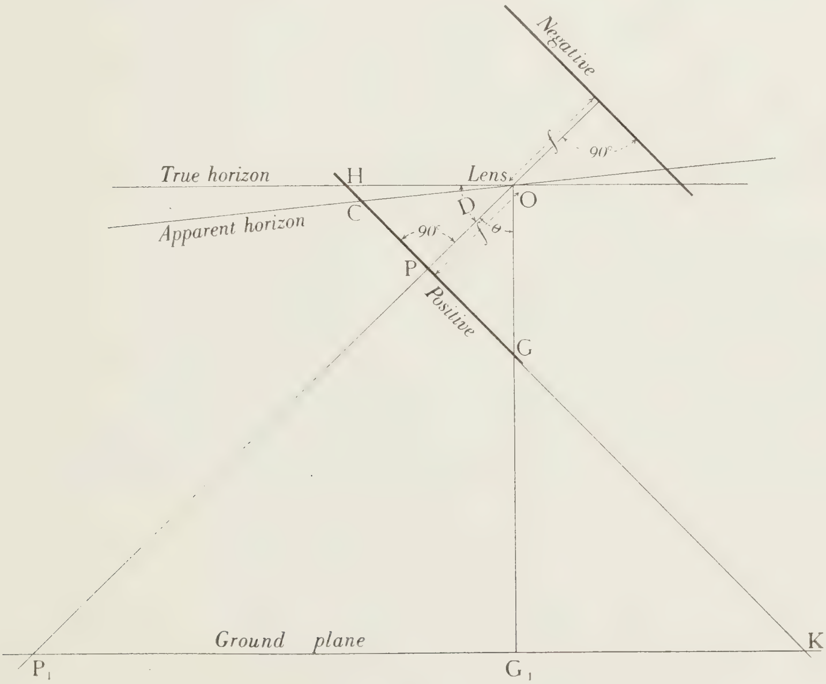


Fig. 7

Fig. 7 represents a section by the principal plane of the photograph.

O represents the perspective centre or camera lens rear node.

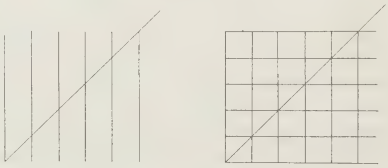
OP represents the normal from the perspective centre meeting the plane of the photo in the principal point *P* and therefore equals the principal distance or focal length of the camera lens.

PC represents the principal line of the photo and meets the apparent horizon line in *C* and the horizontal plane containing the camera lens rear node in *H*.

HOC represents the angular depression of the apparent horizon below the true horizon and is obtained by substituting in equation (1) for *h* the altitude of the aeroplane above the ground when the photograph was taken, as given by the record of the altimeter readings obtained in the flight from which is subtracted the altimeter reading when leaving the ground. At the ordinary photographic altitude of 5,000 feet at which oblique mapping views are taken, an error of 1,000 feet in altitude introduces an error in the apparent horizon dip angle of about seven minutes which corresponds to an error of 0·017 inches in the distance *CH* when using a lens of 8·2 inches focal length, so that for substitution in equation (1) an approximate value of *h* only is necessary.

Referring to Fig. 7, to determine *CH* the distance *CP* is measured in the photograph. The distance $PO = f$ is known from the camera calibration. As the angle *CPO* is a right angle, the remaining sides and angles of triangle *POC* are readily determined, and as the dip angle *HOC* is given from equation (1), triangle *CHO* is readily solved either graphically or by calculation from the known base *CO* and the previously determined angles *HCO* and *COH*. The principal line of the photograph is thus produced from *C* above the apparent horizon to *H* and a normal drawn through *H* to the principal line represents the true horizon line of the photograph. On this line on the photograph are located the vanishing points of all systems of parallel horizontal lines on the ground. Thus, horizontal lines on the ground parallel to the principal plane of the photograph, that is, the vertical plane containing the camera principal line, vanish at the central vanishing point *H* and horizontal lines on the ground making an angle of 45° with this plane vanish at a point distant from *H* an amount equal to *f* sec Dip where Dip = camera depression angle (*HOP* of Fig. 7). Horizontal lines perpendicular to this plane vanish at an infinite distance from *H*, that is, they are parallel to the horizon line.

Perspective Grids.—The information appearing upon an oblique aerial photograph exhibits a large variation of scale. For plotting it to a uniform scale, the method most practical is that of "gridding" the photograph, that is, of applying to it a grid or perspective representation of a system of squares, rectangles or triangles. The particular form of grid to be decided upon should ordinarily be determined by its ease of construction and development both on the plot and on the photograph. In this connection, it might be noted that if a transversal making an angle of 45° therewith be applied to a system of equally spaced parallel lines and through the points of intersection normals to the parallel lines be drawn a system of squares is formed. This is illustrated in Fig. 8.



(a) (b)

Fig. 8

If the direction of such parallel lines be made to coincide with the known principal line of the photograph, the corresponding perspective diagram can readily be constructed. This is done by: (1st) drawing the lines vanishing at

the central vanishing point representing the equally spaced parallel lines, (2nd) drawing each of the two transversals thereto to its respective vanishing point for diagonals which, as stated previously, is located on the true horizon line of the photograph, and (3rd) drawing the lines parallel to this horizon line, through the points of intersection, thus completing the system of squares.

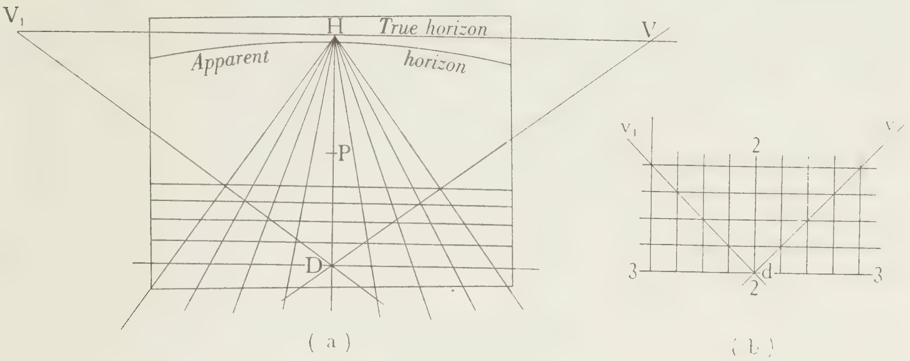


FIG. 9

Thus, in Fig. 9a, which represents the photograph,
- P is the principal point,
- V_1HV is the true horizon line,
- V_1 and V are the vanishing points for lines making angles of 45° with the direction of camera pointing.

To construct a grid on the photograph and the corresponding system of squares on the plot (see Fig. 9b) proceed in the following manner: A number of equal divisions should be ticked off on a straight line drawn on the photograph parallel to its horizon line through any point D on the principal line. Straight lines should then be drawn through such divisions to converge on the central vanishing point H of the photograph. A corresponding system of equally spaced parallel lines such as Fig. 9b, should be drawn for the plot.

On one of the vertical lines of the plot which may be taken to represent the principal line of the photograph, select a point d to represent point D of the photograph. Any point on any of the vertical lines of the plot would effect the same result, but for reasons that will appear later, it is better to make the selection of the point d as indicated. From this point d diagonal lines dv and dv_1 should be drawn and also lines such as 3–3 perpendicular to lines 2–2 on the compilation through the intersection points, thus forming the corresponding plotting squares. On the perspective (Fig. 9a) the diagonals are drawn from D to V and V_1 intersecting the central converging lines. Through the intersection of the diagonals with the converging lines are drawn lines parallel to the true horizon. This completes the perspective grid of the plotting squares.

The squares can readily be made as small as required and the plotting of the area shown in the photograph resolves itself into a square by square transferring by sketching of the topographic detail from photograph to plot. In plotting according to this procedure, no information of the plotting scale is available until the location of two features of a known distance apart have actually been plotted and measured upon the plot.

Uniformity of Grid Construction an Advantage.—If the plotting of a number of individual photographs were to be combined it would be necessary to reduce or enlarge each compilation to a common even scale. This would

involve considerable labour. To offset this, the converging lines are drawn on the photograph so that they represent lines spaced 10 chains or 660 feet apart on the ground and the plotting squares are all drawn to the common scale desired. Referring to Fig. 7, the principal line of the photograph when extended to the ground meets it at K at a distance measured in the photo-plane equal to the altitude of the air position multiplied by the secant of the angle of camera depression below the true horizon. Thus, in constructing our grid for a known altitude of air position we can (see Fig. 10) select the point D on the principal line so that when a distance of one inch is ticked off on the transversal, cutting it at right angles, the line joining such ticked point to the central vanishing point H will when produced meet the ground in the photo-plane at a point 660 feet from the principal plane at K.

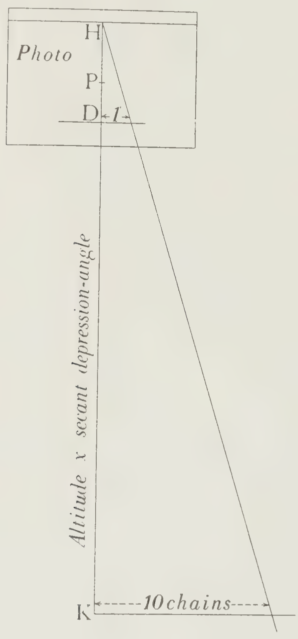


Fig. 10

$$\text{By proportion then } \frac{HD \text{ (inches)}}{1 \text{ inch}} = \frac{HK \text{ (feet)}}{660 \text{ feet}}$$

Thus, if the altitude of the air position is 5,000 feet and the depression angle of the camera is 20° below the true horizon,

$$HD = \frac{1 \times 5{,}000 \text{ sec. } 20^\circ}{660}$$

The one-inch ticks on the line through D can then be joined to the central vanishing point H as before.

It is preferable to have the principal point mark the corner of a grid square and its corresponding point on the plotting sheet will serve as an origin for the plotting. This is readily accomplished if the diagonal lines are drawn through the principal point P instead of any other point on the converging lines. As the plotting squares will then be identical for all photographs, one only need be drawn and duplicates thereof may be made preferably on transparent paper by photo-lithography.

It might be noted that a knowledge of the focal length of the camera lens and the approximate altitude of the air position is necessary for the determination of the camera depression angle where the location of the principal point and the apparent horizon are shown on the photograph. The location of the principal point, as stated before, is etched in its true position on the focal plane plate of the camera in use. The focal length or principal distance is determined by the calibration which is usually done in the laboratory, but the contraction of film from its predevelopment dimensions necessitates, for use in the construction of the grid, a corrected focal length or principal distance, the correction amounting to about one-half of one per cent. Where many photographs are to be plotted it would be a large undertaking to construct on each photograph a grid as described. It has, therefore, been found advisable to construct for each focal length of lens employed a number of grids for depression angles differing by regular intervals and also for altitudes differing by regular intervals, both through a limited range.

In the actual preparation of these grids for regular use, they are drawn to a scale four times their natural size, reduced copies of them being obtained by photographing to transparent glass plates. An endeavour is then made to have all photographs for mapping purposes taken within the range for which the grids are available, a special camera sight and altimeter being used for the purpose. By marking the position of the apparent horizon line on the glass

grid, the true horizon line need not be drawn on the photograph as the former will serve equally well as the latter for the correct super-imposition of the grid on the photograph. Furthermore, in the aerial camera in regular use, a rectangle of dimensions $9'' \cdot 125$ by $6'' \cdot 966$ is etched on the focal plane glass plate marking the limits of the photograph. Instead of determining the camera depression angle as previously outlined, this may equally well be expressed by the distance in tenths of an inch that the apparent horizon line appears to be located below the upper marginal line of the photograph when no swing has occurred. The grid is thus constructed for the depression angle corresponding to a particular position of the apparent horizon on the photograph.

In deciding what intervals of depression angle and of altitude should be adopted so as to keep small the number of grids necessary for plotting a group of photographs, it should be borne in mind that the procedure in taking and plotting these oblique aerial photographs is as follows: Sets consisting of three oblique views, slightly overlapping each other, are usually taken at intervals of not more than two miles along the line of flight. The plotting is carried out on a scale of one mile to an inch, the scale of final publication being four miles to an inch. In the central strip of views an area is plotted in each photograph extending from its principal point, a distance on the ground of one mile towards the foreground and one mile towards the background. If a mapping oblique aerial photograph taken from an altitude of 5,000 feet with a lens of $8'' \cdot 2$ focal length and at a camera depression angle below the true horizon of 19°, were plotted by means of a grid constructed for this altitude but for a depression angle of 19° 20′ instead of 19°, the two-mile distance extending along the principal line one mile from the principal point would measure 10,603 feet instead of 10,560 feet. There would, thus, be a plotting error of 43 feet incurred along the line of flight which on the working scale, one mile to an inch, would amount to $0 \cdot 008$ inches, an error equal to that caused by using a grid constructed for an altitude differing by 24 feet from that which should have been employed in the correct grid of the proper depression angle. A tenth of an inch variation in the marginal distance of these oblique aerial mapping views taken from an altitude of 5,000 feet with a depression of from 18° to 19° corresponds to a variation in depression angle of approximately 36 minutes.

Grids Used by the Topographical Survey.—The Topographical Survey have constructed grids through the range of depressions encountered in taking oblique mapping views of this kind for intervals represented by a tenth of an inch of difference in marginal distance. If the available grid nearest to the marginal distance be employed, the error resulting from this cause will, when the scale of compilation is considered, always be so small that it is practically negligible. The altitude interval adopted in the construction of the grids is either 25 feet or 50 feet. The former is considered to be of slightly smaller interval than the adopted interval of marginal distance would indicate to be required for the same order of accuracy. Each grid is drawn on paper to four times its natural size (as stated before) and then reduced photographically, one or more contact prints as required being made on glass plates from the resulting negative. Before being photographed, the following information entering into the construction of the grid is marked thereon:—

1. The focal length of the lens for which the grid is constructed.
2. The marginal distance of the apparent horizon (instead of the angle of depression referred to the principal horizon).
3. The altitude for which the grid has been constructed.
4. The distance to the ground plumb point from the point where the plate normal meets the ground plane.

The latter, as seen by inspection of Fig. 7, is equal to the altitude of the air position multiplied by the cotangent of the angle of camera depression below

the true horizon. This information is used when it becomes necessary to employ more than one grid in the plotting of different parts of the same photograph, that is, when it is desired to extend the method to plotting areas which depart from a horizontal plane. In this case, the location of the ground plumb point is fixed on each plot and as this point is common to both plots it enables them to be combined. From Fig. 7, it can readily be shown that the photo plumb point is located on the principal line at a distance equal to $f(\tan \text{Dip} + \cot \text{Dip})$ below the true horizon at H where $\text{Dip} = \angle HOP$ or angle of depression of camera axis. The photo plumb point is the vanishing point for vertical lines.

In photographing obliquely, as stated before, the practice is to take at intervals of two miles along the lines of flight a set of three oblique views, in the central one of which the camera is directed in the line of travel over the ground, due allowance being made for the drift of the plane. The principal line of the first central view in a straight flight in which all central views are taken exactly in the direction of ground travel, when extended, would pass through the image points which lie on the principal lines of all succeeding central views. By having the plotted principal lines collinear, the plot of each central view could readily be joined to the next in correct bearing to make a continuous strip. Any relief of the area would not affect the accuracy of the direction obtained by joining image points along this line.

Conditions such as these, however, cannot be fulfilled. Accordingly, for joining plots of successive central views it is the practice to select two image points lying near the principal line of the first central view and, upon the line joining them (and the line produced, if necessary), to choose image points which can be clearly identified on the succeeding central views of each set. In this manner the line may be extended from the start to the end of the flight, that is, from ground control to ground control. These direction points are plotted to establish a straight line common to the successive plots and to ascertain if the length of strip from ground control to ground control agrees with that plotted on the projection or assembly sheet or, if not, the extent of the discrepancy. If, through drifting or other errors of flying, a selected direction line cannot be found that, when produced, will pass through the central views, advantage may be taken of the common vanishing point in the true horizon line of the photograph to establish on each succeeding photograph as required a parallel direction. Or since it is preferable to keep the direction line as near as possible to the principal line of the photograph, the former may be deflected at a point on it by noting where the direction line as deflected intersects the true horizon line of the photograph. By referring to Fig. 7, it can easily be shown that the distance along the horizon line from the principal line to the vanishing point for a horizontal line making an angle ϕ with the principal plane is equal to $f \sec \text{Dip} \tan \phi$ where Dip represents the angle of camera depression. The angle between the original and the deflected direction lines is thus readily obtained by referring each of them to the principal line. The direction line as deflected can still be used for the purpose of controlling the azimuth of the strip plot. When the plot of the central views has been adjusted throughout its length, the plots of the photographs, joining it at either side, are tied to it by the features shown in the area of overlap.

MAPPING FROM OBLIQUE AERIAL PHOTOGRAPHS

Photographing the Area to be Mapped.—Previous to going into the area which is to be photographed, the navigator, who accompanies the aeroplane on its photographic flights, is furnished with the best existing map of that area, on which the various projected photographic flight lines have been laid down in their respective positions. For economic mapping the photographic lines of flight must be laid down in such manner as to allow continuous photography during the operation of the plane.

In this connection, it is to be noted that while it is possible to obtain good photographs with the plane flying in a northerly direction, obviously a return flight with the plane facing the sun cannot give the best results photographically. On this account the photographic lines of flight are usually laid down in parallel lines running in an east and west direction.

For a flying altitude of 5,000 feet above the ground surface, these lines are spaced six miles apart. The areas when the lines of the Dominion lands system of survey have been laid down in whole or in part, can thus be made to readily fit in with base lines, with east and west township outlines, or with other subdivision lines, which may serve as ground control. In other areas, control must be otherwise provided. A very suitable condition exists when the flight lines commence and terminate at points controlled by ground survey and pass over intermediate controlled points at intervals of about 20 miles. However, this condition seldom obtains and recourse must often be had to other methods of providing the necessary control (see Fig. 11).

By experience in mapping to the four-mile scale from oblique photographs it has been found quite practicable on flight lines to "carry a good azimuth" for considerable distances between and beyond controlled points. Therefore, lacking ground control at any twenty-mile interval, if a northerly flight line —itself controlled by passing over two or more surveyed points—is flown to intersect the main east and west flight lines, the points of intersection may be made to serve as subsidiary control.

Along flight lines the oblique aerial views are taken in fan-shaped sets of three, the central photograph of the fan looking ahead along the line of flight and the two-side photographs being taken at angles of 45° to the line of flight, the overlap in each case amounting to about 25 per cent.

The sets are taken at intervals of about two miles so that the greater portion of the photographic detail appearing on one set is duplicated in the next succeeding set (see Figs. 13A and 13B).

Monumented traverse surveys shown thus

Flight lines shown thus...

FIG. 11.—Projected Flight Lines to cover Four-mile Map Sheet.

In this sheet, covering two degrees of longitude and one degree of latitude, in territory previously almost entirely unmapped, the heavy full lines indicate lines of control (monumented traverse surveys) and the broken lines the projected lines of flight for the taking of mapping oblique aerial photographs.

Flying at an altitude of 5,000 feet with flight lines spaced about six miles apart this arrangement will allow the side pictures of adjacent flight lines to overlap at a distance of about two miles beyond the centres of the prints, thus allowing the whole area to be completely covered. The time of taking each set of pictures is recorded, as well as a reading upon a sensitive aneroid barometer, the latter giving the barometric elevation of the plane at the instant of exposure.

Since each photograph represents a different perspective and since the photographs vary according to the altitude of the plane and also according to the tilt of the camera, they must be treated separately. They are first reduced to their respective plans at a uniform scale, generally that of one mile to one inch, which is the scale of the projection sheet. This treatment is termed "plotting the photographs" and is accomplished by means of a perspective grid on a transparent base, described in the previous chapter of this bulletin (see Figs. 4 and 5).

These separate plans or "plots", as they are called, must then be placed in their correct relationship on a projection sheet upon which the ground control has been plotted. This is the real problem which confronts the cartographer. Towards its solution uniformly successful methods have been adopted which may be briefly described as follows.

The various flight lines are first oriented and adjusted with the ground control. They are then correlated and adjusted with each other. The projection sheet is thus covered by a network made up of a series of east and west lines representing the principal flight lines crossed by lines representing ground surveys and northerly flight lines.

Then commencing at the flight line possessing the strongest ground control throughout the greatest portion of its length, the individual pictures are correlated, oriented and adjusted to each other. The adjacent flight lines are dealt with in like manner until the whole map has been built up.

Azimuth Lines.—In order to orient the flight lines between the control points a simple method of alignment is adopted known as an "Azimuth Line" method. Its essential feature consists merely of a straight line drawn on the central pictures of the various sets in the flight line, in the direction of the line of flight and passing from one control to another, thereby governing the flight in azimuth.

Generally speaking, in the type of country to which mapping by oblique aerial photography is adapted, the maximum change in ground relief is not over 200 feet. This marks the change in elevation from water areas to the hilltops. The elevation at which the water areas themselves lie is more or less constant. Hence the intersections of a line drawn on the photograph with the boundaries of these water areas may be considered to lie all in the same plane on the ground. An exception to this assumption would occur when there are rapids or falls indicating a rugged country with various water areas lying at entirely different elevations.

Any straight line on the ground will appear as a straight line on the photograph when the ground is level. Over sloping ground, however, the only straight lines which will appear straight on a photograph will be those which happen to pass through the ground plumb point.

The photo plumb point for the regular oblique mapping photograph falls beyond the photo limits. The straight line which can most readily be drawn to pass through it is the principal line of the photograph, that is, the line passing through the principal point or centre of the photograph and perpendicular to the apparent horizon. For this reason, and in order that the azimuth line may not deviate too far from the central portion of the field of view and disappear to one side when produced through successive photographs, it is necessary to keep it as near as possible to the principal line of the photographs.

Drawing an Azimuth Line.—To draw an azimuth line on the central set of pictures of a flight it is best first of all to lay them out in the order in which they were taken so as to readily determine the tendency of the plane to drift or waver. Drift is the inclination of the plane to depart from the flight line projected on the map due to wind; it generally results in a curved line. Waver is the tendency of the plane to depart from the flight line in a more or less zigzag manner due generally to the pilot being unable to pick up a sufficient number of prominent ground features en route for orienting his flight.

If the water features in the extreme background of one picture disappear off at the left-hand side of some of the later photographs then the plane is swinging to the right. A projected azimuth line drawn to these features would also pass off the pictures at the left-hand side, so that, in order to lay down an azimuth line throughout the entire series, it must be commenced to the right of the principal line. Similarly, if the plane is seen to be swinging to the left, the azimuth line must be commenced on the left-hand side of the principal line. A brief inspection will reveal the extent of deviation, if any, and in practice it has been found better on long flights to start drawing the azimuth line on the pictures covering the middle portion of the flight.

Having made this preliminary study, the azimuth line is then drawn. On the first photograph selected two well-defined objects are connected up in laying it out. These may consist each of the point of an island, a point of land on the shore of some lake, or some other equally prominent point, one being in the extreme foreground and the other in the extreme background of the picture. As succeeding pictures are treated, the latter point will, of course, approach to the foreground of the photographs. It should be noted that in the type of country usually mapped by this method the water features are the most prominent general features recognizable.

Several well-located points on this line, such as for instance those on lake shores or in marshes, which can be readily identified on the adjoining central picture are now chosen and their locations are carefully pin-pricked upon it. A straight line is drawn through these points and on the succeeding picture the procedure is repeated, other prominent points being selected when required. In this way the common line is carried through all the central pictures of the flight until it is produced from one control to another.

Generally speaking, when the pictures are taken at an elevation of 5,000 feet if the pilot has maintained a reasonably straight course, a line may thus be successfully carried throughout the entire flight without departing more than three-quarters of a mile from the principal line. When they are taken at 4,000 feet this amount would be about one-half mile.

When there is a greater deviation, a new line should be tried out, preferably one parallel to the original azimuth line. This latter is chosen in preference to another to facilitate in later adjustments which may have to be made along these lines. Since parallel lines meet at a point on the true horizon and as the position of the true horizon is given on the plotting grid, this can be transferred to the picture, and the new line then established parallel to the old azimuth line by drawing it to the point of intersection of the original azimuth line with the true horizon.

Scale Control Points.—Having completed the azimuth line, or series of lines as the case may be, we must now decide upon the scale of the pictures. In other words, we must determine upon the proper grids which are to be used in plotting the pictures.

To do this choose two points on each central picture, one of which is common to the succeeding picture and the other common to the preceding picture. If, by means in each case of the proper grid, these points were plotted, as well as the portion of the azimuth line nearby, and if their separation distances in the direction of the azimuth line or as projected thereon, were scaled off, the sum

total of these distances will give a result representing the length of the flight from control to control. It should agree with the true distance between controls as shown on the projection sheet.

In practice, in choosing these two points in each picture, one is selected in the extreme foreground which will appear at about the middle of the preceding picture and the other far enough ahead to appear in the foreground of the following picture. They should, whenever possible, be at water level at points where the view of the shore line is unobstructed and easily identified on the neighbouring pictures. Where it is not possible to have them at water level they may be upon marshes or low-lying land—never upon hilltops or undulating country. The reason for this is to keep at a minimum any possible errors which might occur due to changes of elevation. They should be placed on the outlines of water features as far as possible from the azimuth line, since the distance from each of these points to the azimuth line is used to calculate the altitudes at which the pictures are taken, thus checking the barometer readings.

On the initial and final pictures these points should coincide with points established by the ground control systems. If no barometer readings have been furnished, two sets of scale control points on opposite sides of the azimuth line should be made use of on each picture and as, by these alone, the scale must be carried from control to control, they must be as far apart as possible in order to detect by means of a grid any change in altitude of 50 feet or more. (Flying at 5,000 feet, a change of 50 feet in altitude between pictures causes a change of 0·8 of a chain in two points spaced 80 chains apart or 1/100 of an inch at the scale of the projection.) The points should also be placed as low down in the foreground of the picture as possible in order to take advantage of the larger scale of the grid there. It should be here stated that the accuracy and entire progress of compiling a map by the method described is seriously affected by the lack of barometer readings. The latter actually should be considered essential to the work.

Determining the Grid Elevations for the Initial Photograph.—In determining the altitudes at which the photographs were taken, recourse is therefore had, where at all possible, to the barometer readings recorded as each set of pictures is taken. These readings are put down in a form as shown in Fig. 12. The time and barometer readings are noted when the plane leaves the base, when each set of pictures is exposed throughout the flight, and again when the plane returns to the base.

The temperature is also recorded upon leaving the base, upon returning thereto, and several times throughout the flight, so that when conditions warrant, a correction for it may be applied. This correction may be taken as two feet per thousand feet of elevation for each degree Fahrenheit by which the average air column temperature differs from fifty degrees Fahrenheit. It is to be added to the height obtained for temperatures above fifty degrees Fahrenheit and subtracted when the temperature is below fifty degrees Fahrenheit.

Example: Average air column temperature = 35°F.
Height of plane from aneroid readings = 5,000 feet.

$$\text{Correction} = (50 - 35) \times 2 \times \frac{5{,}000}{1{,}000} = 150 \text{ feet.}$$

Hence true height of plane = 4,850 feet.

The difference between the barometer reading at the base and that of the first set taken above the ground control, properly corrected for temperature when necessary, gives the elevation of the first set of photographs above the base. Correcting this for any difference in ground elevation between the base and the ground control the altitude of the plane above the ground control is obtained. This furnishes the approximate elevation of the first set of photographs and

must be checked by applying to the photograph containing the ground control a grid of that elevation.

How to Use the Grid.—(1) As before noted, the principal point is usually etched as a cross on the glass plate in the focal register of the camera lens, and is thus recorded on each negative and on prints therefrom. However, if it is not so marked, locate it by joining the opposite collimating marks.

(2) Measure the marginal distance, that is, the distance from the apparent horizon to the marginal edge of the photograph along the line passing through the centre of the picture and perpendicular to the apparent horizon.

AERIAL PHOTOGRAPHY

Operation Order T.S. 95 Flight No. Aeroplane V. B. Date June 26. 1929.

Leave Thicket at 10 . 15 Aneroid Bar T.S. 1382 Reading 1600 Time 10.15 Temp. 66°

Arrive Thicket at 14. 15 Aneroid Bar T.S. 1382 Reading 1760 Time 14.15 Temp. 62°

Total length of flight 240 miles. Photographic mileage 140

FILM ~~F~~.A. I. M.51.

Camera K. 3. 14. Cone K. 3. 14. 8. Filter Aero I. Exposure 1/50

Location From South end, Northward up line 18 to Birch Tree Lake

Weather Very bright, horizon clear, a few cloud shadows toward end of roll very bumpy

Time	Aneroid	Altimeter	Pict. Sets	Temp.	Calc. ~~Med.~~ Elev.	Remarks	Time	Aneroid	Altimeter	Pict. Sets	Temp.	Calc. ~~Med.~~ Elev.	Remarks
111800	6530		1	40°	4850	Set of 3	114630	6700		61		5010	Sets of 3
111930	6840	5300	4		5150		114800	6300	4700	64		4610	" "
112100	6640		7		4950	1 extra East	114930	6190		67		4500	" "
112230	6730		11		5050	of baseline	115100	6010	4500	70		4310	" "
112400	6540	5000	14		4850		115230	6120		74		4420	Sets of 4. 1 extra left
112530	6460		17		4770		115400	6700	5100	78		5000	" "
112700	6770		20		5080		115530	6520		82		4820	" "
112830	6570		23		4900		115700	6360		86		4660	" "
113000	6340		26		4650		115830	6220		90		4520	" "
113130	6340	4800	29		4650		120000	6150		94		4450	" "
113300	6400		32		4710		120130	6000	4500	98		4300	" "
113430	6950	5400	35		5260		120300	6120		102	40°	4420	" "
113600	6870		38		5160								
113730	6860	5400	41		5150	1 extra R							
113900	6940		45		5250	1 extra East							
114030	6940	5500	49		5250	on baseline							
114200	7060	5600	52		5370								
114330	6640	5100	55		4950								
114500	6720		58		5030								

FIG. 12

(3) Note the serial number of the lens used during the operation and ascertain its focal length from the camera records.

(4) Ascertain from the barometer records the approximate altitude at which the picture was taken.

(5) Having selected a grid which will most nearly conform to the above requirements superimpose it on the photograph so that the principal line of the grid passes through the principal point of the photograph and the apparent horizon on the grid lies along the apparent horizon on the photograph.

The apparent horizon line on the grid is a straight line and the apparent horizon on the photograph is slightly curved. When the grid is correctly placed on the photograph, the horizon line on the grid should coincide with the horizon line of the picture at the intersection of the principal line with the apparent horizon and will be slightly above the horizon line on the photograph at the edges.

(6) Now upon the squared plotting paper draw in the required information square for square as shown by the intersections of the grid lines. The plotting paper used is thin transparent paper on which are printed large squares whose linear dimensions measure one mile at the scale at which the map is being compiled. These large squares are subdivided into smaller squares representing ten chains on the map and corresponding to the small subdivisions on the grid.

Obtaining the Grid Elevations of the Sets.—The initial picture is now taken containing the two "scale control points," that is, the two points which have been identified in the ground control system and whose distance apart on the ground is therefore known. The grid is now selected which most nearly conforms to this picture in focal length of lens, marginal distance, and altitude as approximately obtained. This is superimposed on the picture and a graphical determination of the grid distance between the two scale control points on the photograph is made by transferring them to the plotting paper and scaling the distance between.

If this distance does not agree with the actual distance as measured on the ground, then the wrong grid elevation has been used.

The correct grid elevation is then obtained by the formula:

$$\frac{\text{Correct grid elevation}}{\text{Grid elevation used}} = \frac{\text{Correct ground distance}}{\text{Distance as obtained by measuring on grid}}$$

Having thus obtained the elevation above the ground control at which the picture was taken this elevation is now compared with the barometric reading recorded for this photograph and a correction factor thus obtained to apply to barometric readings of the succeeding sets. Going now to the picture taken over the next ground control, in like manner is obtained the elevation above that ground control at which the picture was taken and, by a comparison with the recorded barometer reading for that set, a second correction factor.

These two correction factors generally agree very well. When, however, a slight difference occurs due to a change in atmospheric pressure or ground elevation, it may be distributed proportionately among the intervening sets unless for some specific reason a different treatment is indicated. The latter case might occur for instance when the first few sets are taken over a lake and the remainder over a stretch of country higher than this lake. The first correction factor would then naturally apply to those pictures covering the lake and the remainder could be corrected proportionally.

We thus obtain a corrected elevation for every set of pictures. These elevations should be marked on the centre picture of each set for the guidance of the plotter. They will serve for the initial plotting of the azimuth line and scale control points; and when a uniform altitude has been maintained by the photographic plane the resulting scale will be such that very little extra adjustment is required.

However, the reading of the barometer readings is done under rather severe conditions so that errors in recording may occur, even to the inadvertent skipping of a set; again the plane may change in altitude so rapidly that the barometer lags. Thus, for several reasons, it has been found necessary to check the elevations derived from the barometer readings by means of the scale control points.

Plotting the Azimuth Line and Scale Control Points.—With the elevations for each set thus determined, the azimuth line and scale control points are now plotted from each central photograph on sheets of plotting paper, one sheet being used for each photograph. They are indexed with the roll number of the flight and the individual number of the respective print.

This procedure is carried on throughout the series of pictures, making such changes in grid elevations as are necessary to have the plots agree in scale between the scale control points common to each picture and the azimuth line. This finally takes the form of a sort of trial line from one ground control to another.

When there are no barometer readings, the elevations from each picture must be calculated by measuring the distance between the two scale control points on opposite sides of the azimuth line on each picture and comparing it with the distance between the same points on the adjacent picture. In actual practice it will be found better to work from both ground controls to the middle of the strip rather than to carry the elevations throughout the entire series of pictures. In this way the elevations are carried the shortest possible distance from that one established directly from the ground control, thus keeping at a minimum errors from changes in ground elevation.

Assembling the Centre Plots.—To assemble the plots, a strip of transparent paper of sufficient length to stretch from one ground control to the next is now taken and a straight line is drawn down its length corresponding to the initial azimuth line. The first plot is now placed beneath and oriented so that the azimuth line on the plot is coincident with the line on the strip of tracing paper. The ground control and scale control points are now traced through and lettered as in the plot.

The next successive plot is now placed beneath the strip, oriented as to azimuth line and adjusted so that the corresponding scale control points coincide. The scale control points on this plot are then traced and lettered.

This procedure is followed from plot to plot until the plot containing the next ground control is reached.

We now have a trial line extending from one ground control to another which has to be made to fit between the corresponding ground controls on the projection.

Adjusting Points.—This strip of tracing paper is now placed upon the projection sheet and oriented so that the azimuth line passes through corresponding points on the ground control systems.

If, when superimposing the initial ground control points on the tracing over the corresponding ground control points on the projection sheet, it is found that the final ground control at the other end of the tracing does not coincide with that on the projection sheet, then the elevations of the grids used in plotting the pictures must be increased or diminished according as the plotted distance between the controls is smaller or greater than the true distance.

The adjustment of this lack of correspondence must depend on the nature of the ground elevations. If the intervening country is assumed to have a constant elevation, then it may be distributed uniformly by a uniform change in the successive grid elevations. But if, for any reason, a more pronounced change in ground elevation is assumed in any particular portion of the flight then, of course, the plots covering this particular portion will be more greatly

affected and the grid elevations should be changed accordingly. If the error is less than one per cent the points can be moved proportionally without changing the grid elevations.

Having decided upon the probable source of the lack of agreement the photographs involved are then replotted and the strip made to fit between the ground controls.

The strip is now laid down on the projection sheet with the plotted ground control positions superimposed on the corresponding ground control positions thereon. The azimuth line and the scale control points are then transferred by means of carbon paper, the points being lettered as on the photograph for identification purposes.

In practice, it is better to plot and transfer the azimuth lines of each flight first of all before transferring any of the topography. With all the flight lines laid down in this way, it is at once seen how successful the pilot has been in adhering to the six-mile interval between flights. In some cases the distance between the flight lines will be found much greater than six miles. In this event the side pictures will have to be plotted farther into the background. Furthermore, with all the flight lines laid down in this manner it is possible to check one with another by plotting some feature common to both, further adjustment at these points being made when necessary. If this is done at this stage considerable trouble in fitting topography later on may be avoided.

Preparing the Photo-prints for Plotting.—In preparing the photo-prints for plotting, it is well to remember that the foreground of the picture more nearly resembles a vertical view and, of course, gives the more accurate representation of ground conditions.

Examination and intense study of photographs is most trying upon the eyesight, the effect being even more pronounced when such examination is carried on underneath a glass grid. To reduce the eye strain and to insure against unnecessary duplication in the actual plotting, the information required to be plotted from the photographs is first of all traced over on the prints with chinese white or aero white ink. This offers a good contrast to the grey and black background of the photograph; it is quite easily put on with a fine pen and quite as easily erased, by merely moistening the finger and rubbing it out when, for any reason, it is desired to remove it.

It is found in practice much easier to work from the end of the flight line towards the beginning since one may always have before him the previously prepared set, indicating at a glance how far into the background it is necessary to study and outline the topography on the succeeding photographs. In this manner a great deal of duplication in inking in the pictures and in subsequent plotting is avoided and the full value is obtained from the foreground of each set.

When outlining the information to be plotted it is important to remember that the photograph has been taken at an oblique angle and consequently near sides of features such as lakes and rivers may be partially obscured by the banks, trees, etc. This must be allowed for and the line drawn back sufficiently to give a correct representation of the true positions of such features.

Plotting the Photographs.—The photographs are now plotted, usually employing for the side pictures grids constructed for the same elevations as were used for the centre one of the corresponding set. In order to tie the plots of the side pictures to those of the corresponding centre pictures, two common points are chosen on each picture known as "tie points."

As the positions of the side plots depend on these points great care should be taken in their selection. They should, whenever possible, be at water level and sufficiently far apart to insure against errors creeping in, due to improper orientation.

The plots of the central pictures are now superimposed on the projection sheet along the azimuth line, they are fitted to the adjusted positions of the scale control points, and the plotted information transferred by means of transfer paper. The plots of the side pictures are then superimposed and adjusted so that the tie points common to both centre and side pictures coincide, and the plotted information upon them also transferred. The principal point and the direction of the principal line are also transferred and the number and roll of the picture marked thereon, thus forming a complete index of the flight.

Occasions may arise when it is necessary to plot features having different known ground elevations appearing on the same picture. Such a case would occur, for instance, where a small lake or lakes would lie in a plateau bordering upon a large water area. The difference in the water elevations in such cases might amount to as much as 100 feet or more.

To plot the topography here two different grids are used for the two different ground elevations. In each case the ground plumb point and principal line are carefully marked on the plot. The ground plumb point is constant for the two plots and by superimposing one plot on the other with the ground plumb points and principal lines coincident the true relationship between the features is obtained.

If the elevation of the larger water area is known and that of the smaller lakes upon the plateau is not known, the true positions of the latter can always be obtained by drawing on the plots radial lines to the plotted positions of points on their shore-lines from the ground plumb points of different pictures. The intersections of such lines as derived from successive plots will give the true position of any points on the shore-lines and thus locate the features.

Summary of Oblique Plotting Method.—Summarizing the above method, first of all draw the azimuth lines on the central prints of the flight and mark the control points necessary to carry on the picture traverse. Then plot the azimuth lines and control points. Fit the strip and adjust between the ground control surveys. Transfer the azimuth lines and control points to the projection sheet and record the corrected elevations at which the various sets are to be plotted. Whiten in the detail which is required from the photographs and the side or tie points to connect the side pictures with the central ones of the corresponding set. Then plot the pictures and transfer the plotted information to the projection sheet.

After all the pictures involved in the sheet are thus dealt with, they are all carefully gone over and inspected for omissions which sometimes occur, chiefly in that portion of the map which lies between flights in the background of the side pictures. One of the chief difficulties in oblique mapping is in identifying creeks, and all drainage should be carefully checked up at this stage.

In order to achieve the best results, the horizons must be clearly defined, and the pictures should be clear and free from cloud shadows. The flight lines should be spaced as correctly as possible, thus avoiding the necessity of plotting far into the background of the side pictures. As the difficulty in plotting the scale control points is increased with the distances between sets, these should not exceed two miles. The ground control should also be readily recognizable on the photographs.

With these conditions maintained it is possible to produce, at much less cost, a map which will for the scales used compare very favourably with one compiled from vertical photographs.

Fig. 13A.—The above—together with Fig. 13B below—illustrates two sets of oblique aerial photographs with accompanying plot of information secured therefrom.

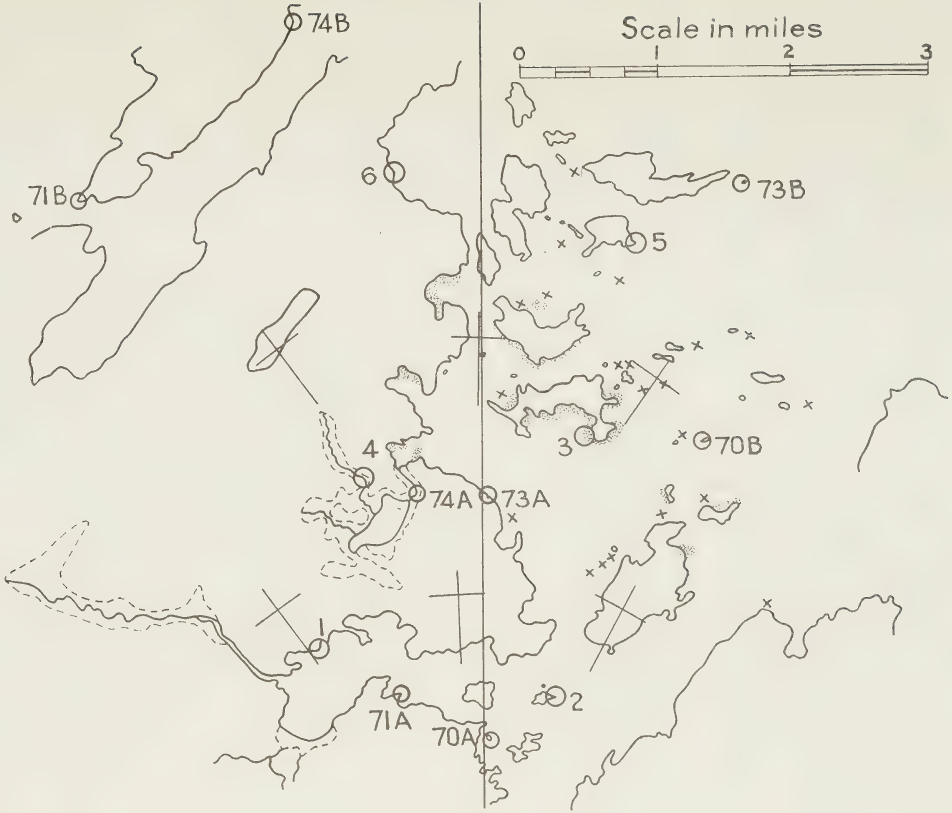


FIG. 13B.—Plot of information secured from two sets of oblique aerial photographs above. The straight line passing through the centre pictures is the azimuth line. The points numbered 1, 2, 3, 4, 5, 6 are the scale control points. The points numbered 70A, 70B, 71A, 71B, 73A, 73B, and 74A, 74B, are the side tie points.

THEORY OF PLOTTING FROM VERTICAL AERIAL PHOTOGRAPHS

A vertical aerial photograph as used by the Topographical Survey for mapping purposes is one taken from an air position usually about 10,000 feet above the ground, with a previously calibrated fixed-focus air survey camera so held that the plane of the negative at the time of exposure is horizontal or as nearly horizontal as practicable. It is given an exposure long enough to produce under good light conditions a suitable negative, but limited so that the track of the image point caused by the motion of the plane in the time represented by the camera exposure interval will not be such as to prevent sharpness in the resulting view. As such photographs are rectangular in shape and are usually taken in straight flights, it is the practice when photographing to orient the camera in the vertical axis position in such a way that the side of the photograph is parallel to the direction of travel over the ground, the succeeding photographs overlapping squarely along this line of flight. In the camera regularly employed, which is equipped with inter-lens shutter, film roll negative, and with lenses of approximately 8″, 10″, 12″ or 20″ focal length, mounted in interchangeable cones, the size of the exposure area is approximately 7″ x 9″. Contact prints are made for mapping purposes on semi-matte, double-weight paper.

Scale.—A vertical axis aerial photograph taken over a level area can be compared to a detail plan of uniform scale. The scale of such a photograph is determined by noting the relation which the distance measured on the photograph between two image points bears to that measured on the ground between the corresponding objects.

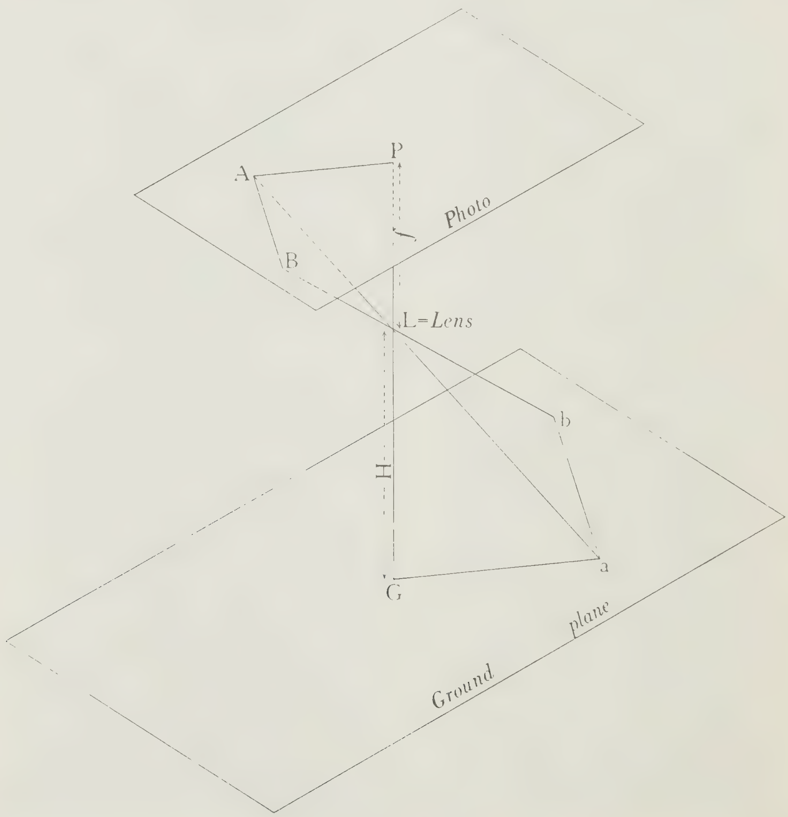


Fig. 14

Thus in Fig. 14:

P represents the principal point of the vertical axis photograph.

L represents the lens position at the time the photograph was taken.

$PL = f =$ principal distance or focal length of lens.

G is a point in the ground plane vertically below L, that is, PLG represents a vertical line.

$LG = H =$ the height of the lens above the ground plane—assumed level.

a and b represent two points in the ground plane, and A and B are their corresponding image points on the photograph; the principal rays from a to A and b to B pass without deflection through the lens centre L.

$$\text{The scale of the photo} = \frac{AB}{ab}$$

As triangles ABL and abL are similar

$$\frac{AB}{ab} = \frac{AL}{aL}$$

and from similar triangles APL and aGL

$$\frac{AL}{aL} = \frac{PL}{GL} = \frac{f}{H}$$

Therefore $\frac{AB}{ab} = \frac{f}{H}$ or the scale of the photo is represented by the fraction

$$\frac{\text{focal length of lens}}{\text{altitude of air position above ground}}.$$

If f is expressed in inches and H in feet, then the photo scale $= \frac{H}{f}$ feet per inch.

The area covered in a photo $7'' \times 9''$ in dimensions is thus a rectangle $\frac{7H}{f}$ feet $\times \frac{9H}{f}$ feet $= 63\left(\frac{H}{f}\right)^2$ square feet, showing that the area covered in one view may be increased fourfold by either photographing from an altitude twice as high, or using a focal length one-half as great.

In photographing an area it is customary to fly parallel flights, taking the exposures at intervals so that each photograph along the flight line will lap the one next to it by 60 per cent. This is usually called "forward overlap." The spacing of the parallel flights is such that each photograph will lap the one adjacent to it on the side referred to as "side overlap"—by 30 per cent or thereabouts. Thus, in practice, the effective area covered in one photograph of dimensions quoted above is:

$$\left(0{\cdot}4 \times \frac{7H}{f}\right)\left(0{\cdot}7 \times \frac{9H}{f}\right) = 0{\cdot}28 \times 63\left(\frac{H}{f}\right)^2$$

or about $0{\cdot}28$ times the total area covered in one view.

Variations in the scale of a near-vertical-axis photograph are introduced by the inclusion of tilt and by unevenness of the ground covered.

Scale Variation Introduced by Tilt.—If, at exposure, the camera axis does not occupy a vertical position, that is, if it is tilted through a small angle, the image points do not all occupy, on the resulting photograph, the same position relative to each other that they would occupy had the plane of the photograph been maintained horizontal. Hence a variation of scale is introduced in the different parts of the photograph. If the extent and direction of the displacement of each image point relative to an origin and direction defined by image points which have suffered no displacement by the tilting of the camera, are determined, a corrected position to each of such image points could be given to which the scale expression $\frac{f}{H}$ would then apply.

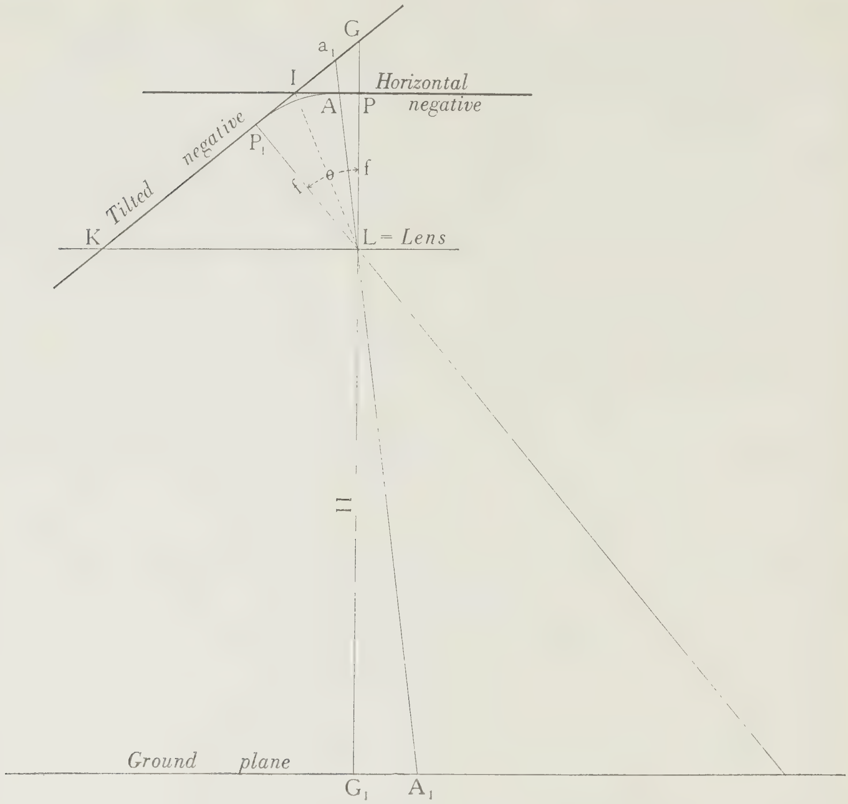


FIG. 15

Referring to Fig. 15:

L represents the back node of the camera lens or the perspective centre of the photograph.

LP represents the principal distance or focal length f of the camera lens.

P represents the principal point of the vertical axis photograph of which IP is a section made by the plane of the drawing.

G_1 is the ground point vertically below the camera lens and its image in the vertical axis photograph IP falls at P.

The photograph IP has a uniform scale represented by the fraction $\frac{f}{H}$ where H is the distance LG_1.

If now the camera is rotated through an angle θ about an axis perpendicular to the plane of the drawing and passing through the nodal point of the lens L, so that P moves to P_1, then,

KP_1IG represents a section of the tilted photograph made by the plane of the drawing and represents the principal line of the tilted photograph.

The point of intersection I is common to the section of the tilted photograph and that of the vertical axis photograph and will thus serve as an origin for measurements made in the planes of both photographs. This point is usually called the isocentre. It is also evident that the plane of the tilted photograph intersects the plane of the vertical axis photograph on a line passing through I and normal to the plane of the drawing, and there is therefore no displacement of image points along this line of intersection.

The vertical line G_1LPG intersects the plane of the tilted negative in G which is referred to as the photo plumb point.

The horizontal plane passing through L intersects the tilted photograph section in K.

The angle $P_1LP = \theta$ is the angle of tilt, the positive direction of tilt on the photo being that towards the photo plumb point from the principal point.

Referring to the triangles LIP and LIP_1 right-angled at P and P_1, as $LP = LP_1$ and IL is a common hypotenuse,

Therefore $$IP = IP_1$$

$$\angle ILP_1 = \angle ILP = \frac{\theta}{2}$$

$$\angle P_1IL = \angle PIL = 90° - \frac{\theta}{2}$$

and $$IP_1 = f \tan \frac{\theta}{2} = IP$$

Let a_1 represent an image point on the principal line of the tilted view, corresponding to the image point A in the vertical axis view of an object A_1 on the ground plane.

Then by reference to Fig. 15:

$Ia_1 = y =$ distance to image point as measured along principal line towards photo plumb point in tilted view from isocentre I.

$IA = d =$ distance from common isocentre I to image point A on vertical axis view.

$y - d =$ tilt distortion in distance y.

Ratio of tilt distortion to total distance measured from isocentre along principal line of tilted view to image point (positive in the direction of photo plumb point) $= \dfrac{y-d}{y} = 1 - \dfrac{d}{y}$

In triangle KIL

$$\angle KLI = 90° - \angle ILP = \angle PIL = \angle KIL$$

Therefore $$KI = KL = f \operatorname{cosec} \theta$$

From the similarity of triangles AIa_1 and LKa_1

$$1 - \frac{d}{y} = 1 - \frac{IA}{Ia_1} = 1 - \frac{KL}{Ka_1}$$

$$= 1 - \frac{KL}{KI + Ia_1} = 1 - \frac{f \operatorname{cosec} \theta}{f \operatorname{cosec} \theta + y}$$

$$= 1 - \frac{1}{1 + \frac{y}{f} \sin \theta} = 1 - \left(1 + \frac{y}{f} \sin \theta\right)^{-1}$$

As θ is small, substitute θ (in radians) for $\sin \theta$ and expand the part in brackets which is rapidly convergent and thus obtain

$$1 - \frac{d}{y} = 1 - \left(1 - \frac{y\theta}{f} + \frac{y^2\theta^2}{f^2} \cdots\right)$$

$$= \frac{y\theta}{f} \text{ approx.} \qquad (2)$$

Example:

$$\text{If} \qquad \theta = 3° = \cdot 0524 \text{ radians}$$
$$\text{and} \qquad y = 4''$$
$$\text{and} \qquad f = 8''\cdot 2$$
$$\frac{y\theta}{f} = \frac{1}{39}$$

and the tilt distortion in the 4″ measurement along the principal line

$$= 4 \times \frac{1}{39} = 0''\cdot 1 \text{ approx.}$$

If the image point whose displacement is to be determined does not fall on the principal line or line of greatest slope in the tilted photograph, assume that it lies at a distance x_1 measured along the perpendicular from a_1 in the plane of the tilted photograph (that is, normal to the section shown in Fig. 15) and let the corresponding distance in the plane of the vertical axis photograph be X, then it is readily seen from Fig. 15 that

$$\frac{x_1}{X} = \frac{La_1}{LA} = \frac{Ka_1}{KI} = \frac{Ka_1}{KL} = \frac{Ia_1}{IA} = \frac{y}{d}$$

$$\text{That is,} \qquad \frac{x_1}{y} = \frac{X}{d}$$

or the tangent of the angle which the line joining the image point to the isocentre makes with the principal line in the tilted photograph equals the tangent of the angle formed by the corresponding lines in the vertical axis photograph, that is, the two photographs are angle true at the common isocentre I.

If then the image point does not fall on the principal line of the tilted view, let ϕ be the angle which the line joining it to the isocentre makes with the positive direction of the principal line—that is towards the photo plumb point—and let r = distance of image point along this line from the isocentre.

Then $r \cos \phi$ = projection of r on principal line,

and $y\dfrac{\theta}{f}$ of equation (2) becomes $r \cos \phi \dfrac{\theta}{f}$,

or total distortion measured in direction of principal line

$$= r \cos \phi \frac{\theta}{f} r \cos \phi$$

Therefore, total distortion in distance r measured along the direction of image point from isocentre, that is, at angle of principal line,

$$= \frac{r \cos \phi \dfrac{\theta}{f} r \cos \phi}{\cos \phi} = r^2 \cos \phi \frac{\theta}{f} \tag{3}$$

For two image points diametrically opposite and equally distant from the isocentre, the tilt distortions are equal and of opposite sign, a useful consideration in determination of air position from scale expression $\dfrac{f}{H}$.

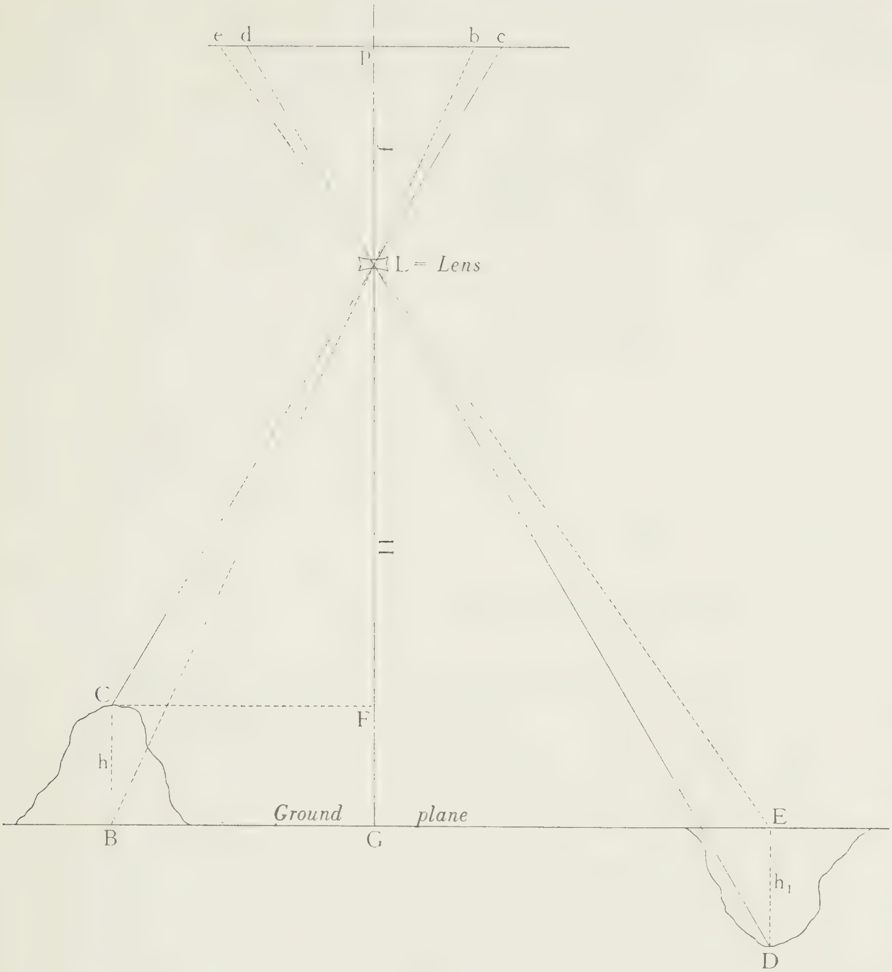


Fig. 16

Displacement Due to Unevenness of the Ground.—In Fig. 16, *dpc* is a section of a vertical aerial photograph by a vertical plane passing through L the rear node of the lens—that is, the perspective centre of the photograph.

p represents the photo plumb point, that is, the point where the vertical through L meets the plane of the photograph.

G is the point where the vertical through L meets the ground plane—that is, the ground plumb point which corresponds to the image point p.

As the camera axis is in this case assumed vertical, p also represents the principal point of the photo.

pL equals the principal distance or focal length f of the lens.

c is the image point corresponding to the object point C which lies a distance h above the mean ground plane.

d is the image point corresponding to the object point D which lies a distance h_1 below the mean ground plane.

H represents the distance from L to the mean ground plane and for objects in this plane, the scale of the photograph is given by the expression $\frac{f}{H}$.

The image point corresponding to the point B in the mean ground plane vertically below C as determined by the point of intersection with the photo plane of the principal ray from B through L is b.

bc is thus a measure of the displacement of image point b resulting from the relief of the ground at C.

It is evident that the location of the photo plumb point p is not affected by the relief of its corresponding object point G.

Now from the similarity of triangles pLc, FLC, and pLb, GLB

$$\frac{bc}{pc} = \frac{pc - pb}{pc} = 1 - \frac{pb}{pc} = 1 - \frac{\frac{pb}{f}}{\frac{pc}{f}}$$

$$= 1 - \frac{\frac{BG}{GL}}{\frac{CF}{FL}} = 1 - \frac{FL}{GL} = 1 - \frac{H - h}{H} = \frac{h}{H}$$

Therefore $bc = \frac{h}{H} pc.$ (4)

Similarly $\frac{ed}{dp} = \frac{h_1}{H}$ and $ed = \frac{h_1}{H} dp.$

That is, the distortion measured on the photograph introduced by the unevenness of the ground is either towards or away from the photo plumb point depending on whether the object point is located below or above the mean ground plane and may be expressed as the (distance of the image point from the photo plumb point) multiplied by (the ratio of the departure of the object point from the mean ground plane to the vertical distance of the lens above such ground plane).

If in Fig. 16 $pc = pd$ and $h = h_1$, then $dc = eb$ and the overall measurement between the two image points is not affected by the relief, that is, if two image points are selected on the photograph which are equidistant from and located on diametrically opposite sides of the photo plumb point, and if H represents the height of the lens above the mean level of their corresponding object points, as determined by aneroid or altimeter readings, then the distance between the two ground points $= \frac{H}{f}$ times the distance measured on the photograph between their image points.

Applying Distortion Effects Resulting from Tilt and Relief.—The method of applying the distortion effects resulting from relief and tilt is indicated in Fig. 17, where

P represents the principal point of tilted photograph,

I the isocentre distant from it, $f \tan \frac{\theta}{2}$,

f = focal length of lens,
θ = angle of tilt,
G = photo plumb point $f \tan \theta$ distant from P,
the points G, I, P, are collinear and are on the principal line of the photograph.
A represents the image of an object located h above the datum ground plane, on the photograph taken from a distance H above the same plane.

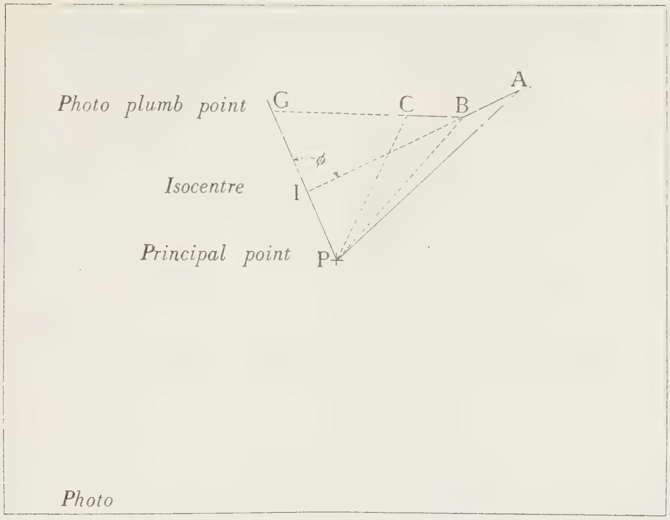


FIG. 17

AB represents tilt distortion

$= (IA)^2 \cos\phi \frac{\theta}{f}$ where $\angle\, GIA = \phi$ = angle which direction from isocentre I to image point makes with direction of principal line, considered positive in direction of photo plumb point, and θ = tilt in radians, and f = focal length of lens.

BC represents relief distortion

$= \frac{h}{H} BG$ where h = elevation of feature above datum ground plane.

To correct for tilt the image point A is displaced along the line AI to B where AB = value given above.

To correct for relief the image point B is further displaced along the line BG to C so that $BC = \frac{h}{H} BG$. C thus represents the final location of the image point A.

To apply these corrections for tilt and relief distortion, a knowledge of the extent and direction of tilt is essential in order that the location of the photo plumb point and isocentre may be marked on the photograph. The absolute tilt of a photograph cannot, however, be determined without reference to ground control whose x, y, z co-ordinates are known, and even then the computation in connection with the determination is rather laborious. The location on the photograph of the principal point is made available in the camera calibration and the extent of the errors introduced on the assumption that the tilt distortion AB of Fig. 17, and the relief distortion BC of Fig. 17, are radial from the principal point will be next investigated, that is, the extent of the error in the assumption that near vertical axis aerial photographs are angle true at the principal point.

The error in assuming the tilt distortion is radial from the principal point, is seen from Fig. 17, to be ($AB \sin BAP$). (5)

From triangle AIP, $\angle\, AIP = 180° - \phi$ and $IP = f \tan\frac{\theta}{2}$

By rule of sines,

$$\text{Sin } BAP = \frac{IP \sin\phi}{AP} = \frac{f \tan\frac{\theta}{2} \sin\phi}{AP}$$

Substituting this for sin BAP in (5)

$$AB \sin BAP \text{ becomes } \frac{AB\, f \tan \frac{\theta}{2} \sin \phi}{AP}$$

and substituting further for AB from (3) writing IA for r

$$= \frac{\left(IA^2 \cos \phi \frac{\theta}{f}\right)\left(f \tan \frac{\theta}{2} \sin \phi\right)}{AP}$$

When θ is small, $\tan \frac{\theta}{2}$ becomes $\frac{\theta}{2}$

and $\frac{IA^2}{AP} = IA$ approximately and the above expression reduces to

$$\frac{IA}{4} \cdot \theta^2 \sin 2\,\phi \qquad (6)$$

This expression (6) reduces to zero when $\phi = 0$ or $90°$ and the greatest value is obtained when IA is a maximum and $\phi = 45°$, as sin 2 ϕ then equals 1.

Example: If $IA = 4$ inches and $\theta = 3°$, or $\cdot 0524$ radians, the maximum value reduces to $(\cdot 0524)^2 = \cdot 0027$ inches, a negligible quantity in graphical plotting.

The error in assuming that the relief distortion BC is also radial from the principal point is seen by reference to Fig. 17 to be

BC sin CBP and substituting for BC from (4) writing BG for pc

$$= \frac{h}{H} BG \sin CBP \qquad (7)$$

Sin CBP is zero when B is on the principal line and the maximum value of sin CBP occurs for any particular value of BG when $\angle\ GPB$ becomes a right angle or as near a right angle as the length of BG permits.

$$\text{Sin } CBP \text{ then equals } \frac{f \tan \theta}{BG}$$

and the above equation (7), giving the maximum extent of error in assuming the relief distortion is radial from the principal point becomes

$$\frac{h}{H} BG \frac{f \tan \theta}{BG} = \frac{h}{H} f \tan \theta \qquad (8)$$

Example:

Assume $h = 500'$ when $H = 10{,}000$ feet and $f = 8''$

When $\theta = 3°$ of tilt, the expression becomes

$$\frac{500}{10{,}000} \times 8 \times \cdot 0524 = 0'' \cdot 02.$$

The effect of tilt and relief errors in the radial assumption are obtained by combining the equations (6) and (7). It might be noted from the above that the direction in which the maximum error in the radial assumption resulting from relief occurs, viz., a direction at right angles to the principal line, is the direction in which the minimum value of the effect from tilt distortion takes place; also, that both of these errors become zero when the image point falls on the principal line of the photograph. As the range of relief in the area covered by a photograph becomes large, the accuracy of the radial assumption breaks down and errors represented by measurements on the ground amounting to (range of relief encountered in one view) multiplied by (the angle of tilt expressed in radians) may be introduced. Thus with a three-degree tilt and range of relief in a photograph of 1,000 feet the radial direction may be in error by $1{,}000 \times 0 \cdot 0524 = 52$ feet. The necessity for maintaining tilts small in

photographs of rough areas is thus indicated, otherwise the photo plumb point must be located in the photograph which involves the determination of absolute tilt—and used in the radial assumption on which the method of plotting is based, instead of the principal point.

Radial Intersection Method for Plotting.—It has been shown that in photographs of level areas or areas of moderate relief where the tilt has been kept small, the displacement of an image point due to tilt and to the unevenness of the ground covered, may be considered to take place along the line joining the image point to the principal point of the photograph. In other words, the photograph may be considered to be angle true at its principal point.

If a continuous strip of vertical photographs is taken along a line of flight with an overlap in the direction of travel such that the image of the principal point of the second photograph is shown in the first photograph, and the image of the principal point of the third photograph is shown in the second photograph and so on throughout the strip, a bearing may readily be "carried" from one end of such continuous strip to the other. In effecting this, the direction common to each overlapping pair of photographs serves for carrying a bearing from one photograph into the adjoining overlapping one; and, in addition, the successive angles of deflection at the principal points of the views can be taken into account.

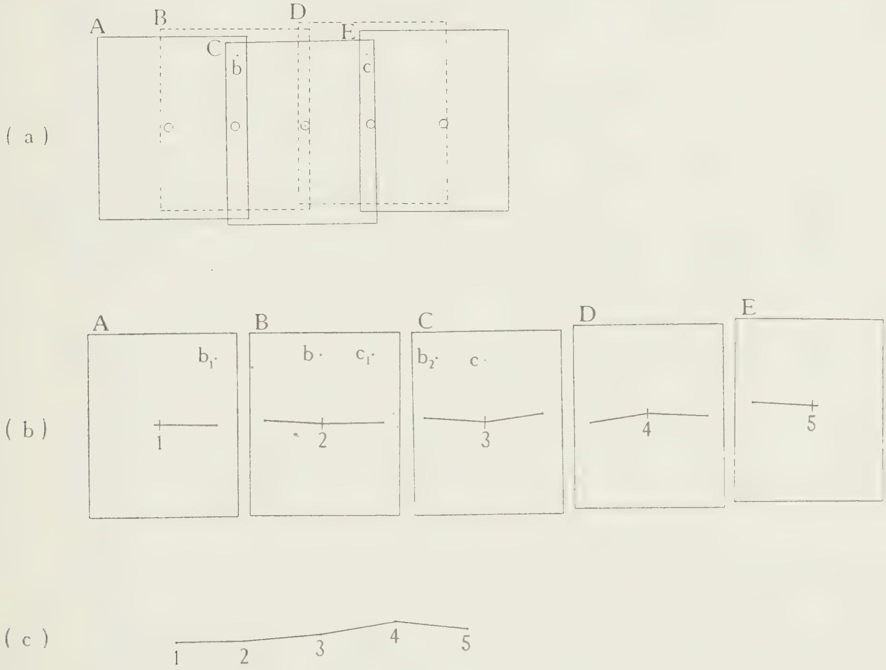


Fig. 18

This is illustrated in Fig. 18 (a), (b) and (c).

Fig. 18 (a) represents a portion of a strip comprising five overlapping photographs *A*, *B*, *C*, *D*, *E*, with their principal points indicated by small circles.

Fig. 18 (b) represents these photographs with their principal points numbered 1, 2, 3, 4 and 5, and radial lines drawn on each photograph from its

principal point to the image points corresponding to the principal points of the adjoining overlapping views, these lines usually being referred to as the principal point bases.

Fig. 18 (c) represents the orientation of these principal point bases in correct alignment but not adjusted to any slight variations in the scales of the various photographs.

The length of a principal point base as measured on one photograph, is affected by the relief of the area, the fore and aft tilt of one view relative to the other, and the difference in altitude between its air position and that of the adjoining view. The result is that it will not necessarily agree with the measurement of the same principal point base obtained from the adjoining and overlapping photograph.

To enable the plotting of these principal point bases to be carried out to a uniform scale such as may have been adopted for that of a previously plotted principal point base, two clearly defined image points are selected on each photograph lying about two or three inches distant for photographs 7 by 9 inches in size from and in a direction from its principal point approximately normal to the principal point base, one on each side of such base. The selection of these points should also be made so that they are on the overlap common to three consecutive photographs. The radial directions to such image points measured on each of the three consecutive photographs will serve to fix to the uniform scale adopted, the length of consecutive principal point bases. One such selected point on each photograph would serve, but two are chosen to provide a check and strengthen the work. Resulting from the overlap, each photograph thus contains, in addition to the two points selected opposite its principal point, the two selected points opposite the principal points of each of the two adjoining views, or six selected points in all.

Referring to Fig. 18 (b), if any image point b on photograph B opposite its principal point 2 and on the overlap common to photographs A, B and C be chosen, the angles which the radial directions to b make with the principal point bases 1–2 and 2–3 can be measured at the principal points of each of the three photographs A, B and C as indicated in Fig. 19.

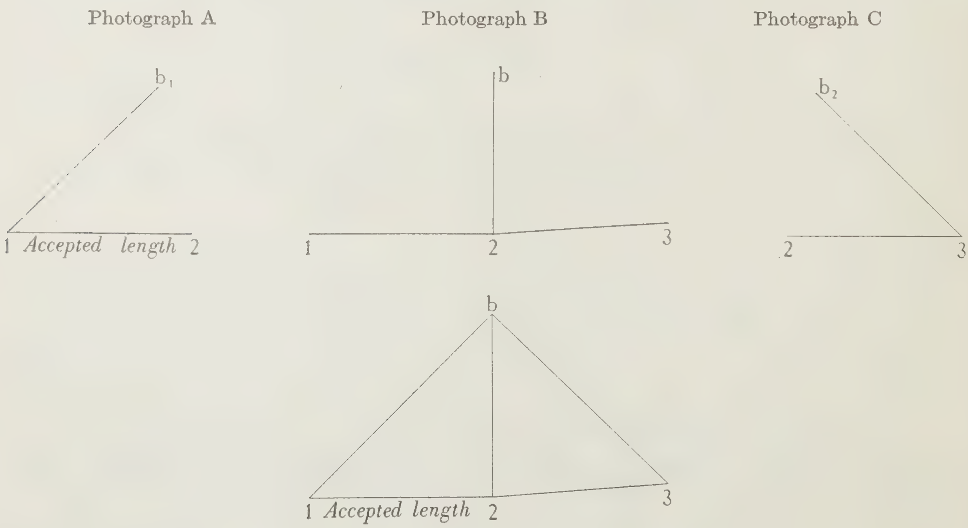


Fig. 19

Accepting the distance between the principal point 1 of photograph *A* and the image point corresponding to principal point 2 of photograph *B* as measured on photograph *A* as the true distance to scale of plotting of the principal point base of photographs *A* and *B*, we can then either graphically or by calculation from the two base angles measured on photographs *A* and *B*, determine the length to the same scale, of the radial line from principal point 2 of photograph *B* to image point *b*. From photographs *B* and *C* we can similarly determine the length of the principal point base common to the latter two views, expressed in terms of the radial line from the principal point 2 of photograph *B* to image point *b*, which latter has previously been determined and expressed to the same scale as the principal point base of photographs *A* and *B*.

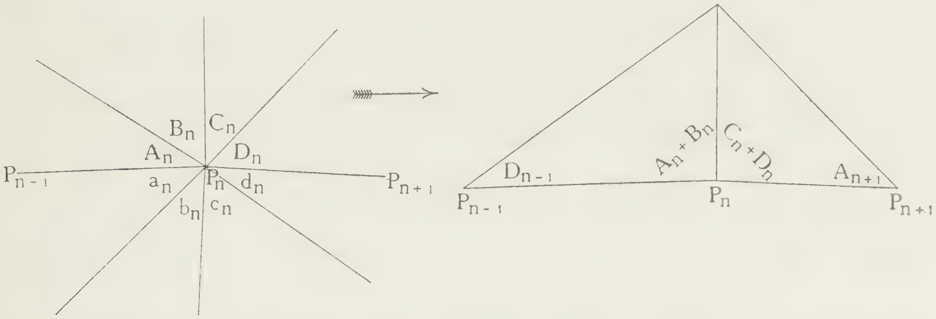


FIG. 20

In this manner the lengths of successive principal point bases may be determined to a uniform scale from the selected points lying on one side only of the line of flight. By using selected points lying on the opposite side of the line of flight a second value of each base may be determined and the mean of the two adopted. The general case is indicated in Fig. 20 which represents the n_{th} photograph of a strip. The angles *A*, *B*, *C*, *D*, and *a*, *b*, *c*, *d*, with suffix *n* attached represent the angles between the radial directions to the selected image points and adjoining principal points as measured on the n_{th} photograph, the arrow represents the direction in which the strip plotting is being carried on and P_{n-1}, P_n, P_{n+1} represent the principal point of the $(n-1)_{th}$, n_{th} and $(n+1)_{th}$ photographs respectively. The length of the principal point base between the n_{th} and $(n+1)_{th}$ photograph may be expressed in terms of the preceding principal point base between the $(n-1)_{th}$ and n_{th} photograph by the following expression, using the notation just given:

$$P_n\, P_{n+1} = P_{n-1}\, P_n \left\{ \frac{\sin D_{n-1}}{\sin (D_{n-1} + A_n + B_n)} \cdot \frac{\sin (C_n + D_n + A_{n+1})}{\sin A_{n+1}} \right\}$$

A second value is determined by substituting for capitals *A*, *B*, *C*, *D*, the angles represented in Fig. 20, by small letters *a*, *b*, *c*, *d*, located on the opposite side of the flight line or principal point bases, and with the same suffixes attached.

Instead of computing these principal point base distances, an operation which involves the accurate measurement of the angles between the radial directions at each principal point, it is more expedient to carry out the construction of the triangles in a graphical manner. This may be done by the use of transparent tracing linen, xylonite or tracing paper. With any one of these mediums the respective radial directions can be traced by superimposing such medium on the photographs on which the principal point bases have been drawn and on which also the selected image points have been accentuated. Owing to the rapidly cumulative effect of any error introduced into the work,

in order to prevent any change of scale, extreme care must be taken in constructing the triangles and checking any discordances which may be detected. The resulting structure for each strip of photographs resembles Fig. 21. In this figure, the dotted portions of the lines are not, in practice, regularly drawn on the plot. To facilitate the transfer of the topography from the photograph to the plot the scale of the strip plot should not depart greatly from that of the photographs involved. Thus the measurement adopted at the commencement of the strip to govern its scale throughout should agree closely with the scale of the terminal photograph. Where this is not possible, a mean scale may be chosen, the information available as to the flying height and relief of the area serving as a guide towards its selection.

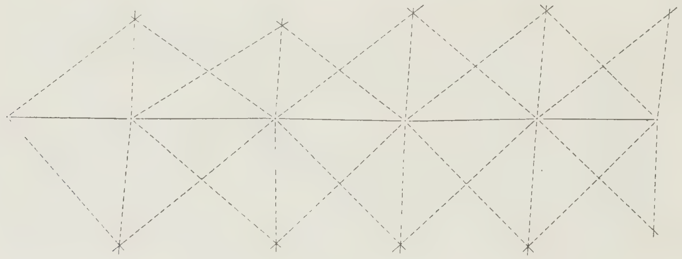


FIG. 21

Where two suitably situated ground control points occur in the overlap common to the first two or preferably the first three photographs of the strip, the scale of the strip plot may be determined by intersecting these two points on the strip plot (by their radial directions) and comparing their plotted positions with their true positions.

Where such ground control points are not available, the scale of the strip plot may be obtained from a reliable record of corrected altimeter readings obtained on the flight. For this case, on a photograph two image points of ground features of known elevations above sea level, and lying equally distant from and on opposite sides of its principal point, are selected. These points are then intersected on the strip plot. The height of the plane above the mean level of the two ground features can then be determined from the flight record. Designate this height by H. The distance between the image points on the photograph are measured and compared with the distance on the strip plot of their plotted positions. The scale of the plot then equals:

$$\frac{\text{plot distance}}{\text{photo distance}} \times \frac{f}{H}$$

where f = focal length or principal distance of camera lens.

It is preferable, however, to obtain a good overall scale for the strip by providing a control point at each terminal of the strip or, where the strip is long, control points at intervals which will serve to break up the long strip into shorter strips. Where the ground is relatively flat and the flying and photography has been carefully carried out, control is usually supplied at intervals of from five to twelve miles. This means that with vertical aerial photographs taken at 10,000 feet with a lens of $8''\cdot 2$ focal length (scale $4''\cdot 33$ = 1 mile) the strip plot is from $22''$ to $52''$ in length. Where the range of relief in the area covered by the strip is large, control at shorter intervals is necessary. Each such control point should consist of a feature tied to the triangulation or traverse survey, which is clearly identifiable on the photographs. It should be so identified and its image point marked by pricking with a fine needle on the contact prnit made on double-weight paper supplied for this purpose.

Before plotting is commenced, it is necessary to carefully mark on the photographs the principal point bases and to accentuate the selected image points used for extending the strip structure. This is necessary so that this information can be carefully traced from the photographs to the strip plot. Where detail is plentiful and identification not difficult, the image point corresponding to the principal point (as shown marked by a cross in the adjoining photograph) is readily transferred and the principal point bases can then readily be established by joining with a fine line in red or white ink the image points corresponding to the principal points of adjacent photographs. Where detail is not plentiful, the direction of the principal point base may be established by noting that in a pair of overlapping views the image points lying on or close to the principal point base are displaced in a direction parallel to it.

Thus, the two photographs of the overlapping pair may be placed on a table with their principal points about thirteen inches apart and fixed to the table in this position by pricking each principal point with a fine needle, which passes through the photograph into the table. This allows each print to be rotated independent of the other about its principal point. By placing a straight edge on the line of the principal points and rotating first one view and then the other, by trial an orientation of the two prints is found such that the line joining their principal points intersects the same image points on each print, or misses nearby image points chosen in pairs on opposite sides of the principal point base by the same amount in each view. When this orientation is determined, the air base line is drawn on the prints. A further description of a similar method is given on pages 69 and 70.

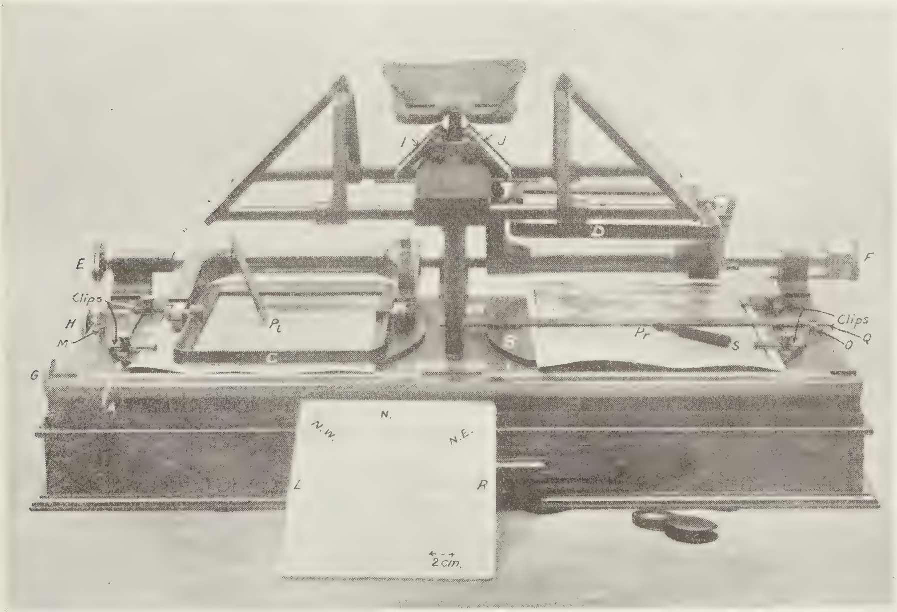


Fig. 22.—English-type Precision Stereoscope.
For explanation see text. Also compare with Fig. 32.

The use of the English-type precision stereoscope illustrated in Fig. 22 offers a most satisfactory means of marking the common principal point bases on overlapping stereoscopic vertical aerial photographs; it recently has supplanted in the office of the Topographical Survey the earlier methods to this end previously described. The illustration shows two prints of a stereoscopic pair set in position for viewing with the right-hand grid plate swung up above

the print. The straight edge is against the stops in position for scratching the principal point base on the right-hand print. This stereoscope resembles somewhat the common form of mirror reflecting stereoscope used for aerial photographs. In it, however, the prints of the pair of photographs to be viewed are placed in approximately correct orientation, but at a fixed separation on the base of the instrument.

Referring to the illustration, the base of the stereoscope is equipped with two turntables, *A* and *B*, each rotatable through a limited range of about ten degrees on fixed vertical axes which are marked with a small needle hole in the centre of each turntable. The left-hand print is carefully placed in approximate orientation for viewing on the left-hand turntable *A* so that its principal point P_l superimposes the small needle hole marking the axis of rotation of the turntable, and is clamped in this position by two spring clips (see illustration). In practice, a cross on the glass grid centre line is made to superimpose the needle hole and then the print to be examined is placed with its principal point under the respective grid cross and in approximately correct orientation. The right-hand print is similarly clamped in position on the right-hand turntable *B* of the stereoscope. To obtain stereoscopic fusion of the prints without strain to the eyes, provision is made for slightly rotating the upper pair of viewing mirrors, *I* and *J*, the effect thereby produced being similar to that of increasing or decreasing the separation of the prints in the ordinary type of mirror stereoscope (see Fig. 32).

Hinged to the base of the stereoscope are two glass grids, *C* and *D*, which normally lie on top of the photographs. Provision exists for moving these grids, together by turning knob *E*, or grid plate *D* only by turning knob *F*, in the direction of their centre line in the down position, that is, in the direction of the line joining the centres of the turntables P_l–P_r. The angular motion of each turntable on which the prints are clamped and held flat by the glass grid plates, is controlled by separate knobs, *G* and *H*. These glass grid plates are etched with fine lines as is shown at *LR* in the figure, this being an extra plate so placed for purposes of illustrating only. The central line *L–R* is parallel to the eye base of the instrument. The grid plates can be adjusted in their holders so that this central line, when the grids are lying in position on the photographs, coincides exactly with the line joining the axes of rotation of the turntables on which the prints are placed.

Fixed on the base of the instrument are three stops, *M*, *N*, *O*, similar flattened sides of which are collinear with the centres of rotation of the turntables and consequently of the prints when properly affixed thereon. When the steel straight edge *Q*, supplied with the instrument, is held in contact with the flattened sides of two of the stops, its edge marks the line joining the centres of rotation of the prints, which line coincides with the central line of the grids. By this means the location of the grid central line may be marked on the prints beneath the grids.

The grid pattern includes a system of squares whose sides are inclined at forty-five degrees with the central line of the grid or direction of eye base of the stereoscope. As these lines have a weak stereoscopic character in comparison with the photographs, they are essential in determining when the photographs have been set in correspondence, that is, when the central line *L–R* of the grid as superimposed over the principal point P_l of one photograph passes through the image point corresponding to the principal point P_r of the other photograph of the pair under examination. It is usual to refer to the lines forming the grid pattern as the NW., NE., and N. lines, the northerly direction being that directly away from the observer when in the viewing position at the stereoscope.

Suppose that a pair of stereoscopic vertical aerial photographs have been clamped in proper position on the turntable base of the stereoscope as described above, and the upper pair of reflecting mirrors have been adjusted to the

observer's eyes for easy fusion of the prints. If the glass grids are now superimposed on the photographs and the observer concentrates his attention on the photographs themselves, by looking through the grids, he will see a relief model or stereoscopic image of the overlapped area covered by the photographs, and, above this, a net formed by fusion of the lines on the two glass grids. By altering the separation of the grid plates, effected by turning the right-hand micrometer head, F, the grid net will appear to rise or fall relatively to the ground. As the plane of this grid net appears to approach the ground the net will, in all probability, break up, the NW. lines crossing the NE. lines in space at different apparent depths. When the two prints of the pair are set in the stereoscope so that the common principal point base of each photograph is in line with the central line of the grid, and the grid plane is brought to ground, it will not break up along the principal point base line.

This desired orientation of the prints should be carried out in a methodical manner. To orient the right-hand print, a grid cross formed by the intersection of a NE. and NW. line should be placed, by shifting the left-hand grid by means of knob E over the principal point P_l of the left-hand print. With the left-hand grid in this position, the right-hand grid is shifted by the micrometer screw head F until the grid plane approaches the ground, and the turntable carrying the right-hand print is rotated slightly by turning the upper left-hand knob H to offset the breaking up of the grid plane in the vicinity of the principal point of the left-hand view. For instance, suppose the image of a feature a (Fig. 23) lies at the left-hand principal point P_l at the intersection of a pair of NE. and NW. lines. Its corresponding image point a^1 lies slightly below the cross formed by the adjacent NE., NW. grid lines on the right-hand photograph.

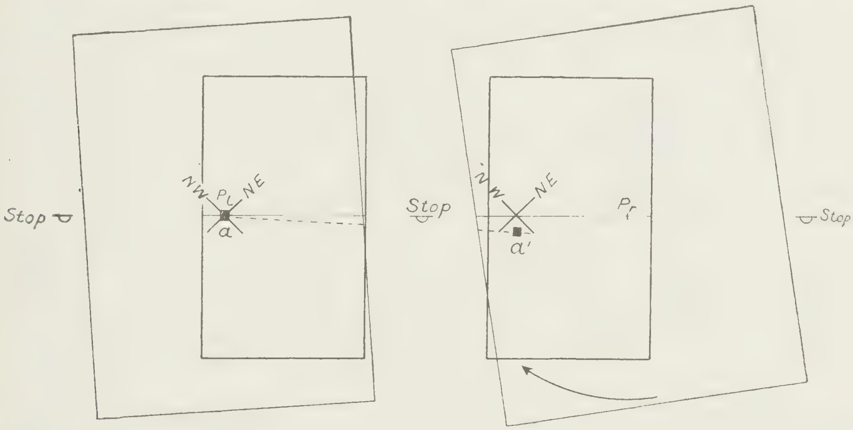


Fig. 23

Now, relative to the two image points a and a^1, of the photographs, which are in strong fusion, the adjacent NW. lines appear to have a greater separation and the NE. lines a less separation. The spatial cross formed by these lines, being relatively weak, will thus break up under the influence of the photographic detail, the NW. lines fusing to form an image below the feature a, and the NE. lines fusing to form an image above the feature a. If by turning knob H the right-hand photograph is now slowly and carefully rotated in the clockwise direction, as indicated, the difference in the separation of the two sets of lines relative to a–a^1 becomes less, and therefore the difference in the depth beween the two lines crossing in space will be gradually lessened and the lines will finally be brought into and cross each other in the same plane. By altering the separation of the grids, that is, by moving the right-hand grid plate by turning micrometer head F, this grid plane may be brought to touch the ground and

then the right-hand print is given, by turning knob H, any slight adjustment or rotation necessary to bring the two crossing lines accurately into the same plane in the neighbourhood of the feature a. The left-hand print is oriented by placing a grid cross over the principal point P_r of the right-hand photograph and adjusting the rotation of the left-hand turntable in a similar manner to the above.

To remove any small discrepancies the operation is repeated, and finally by altering the separation of the grid plates, that is, by turning micrometer head F the grid plane should not break up when brought in contact with the ground at any point along the principal point base. With the prints in this position, the grid plates are swung up clear of the prints (the illustration shows grid plate D so swung up). The alignment rule or straight edge Q is then placed in position on the right-hand print, pressed against the stops NO, and the principal point base is scratched on the print by a needle held in a holder S. The straight edge is then placed on the left-hand print and pressed against the stops M, N, and the principal point base similarly scratched on it.

If in the neighbourhood of the principal point there are no image points capable of giving a stereoscopic image, such as would be the case if the principal point falls in open water, then similar observations should be carried out on detail on the principal point base line in the neighbourhood of the principal point and as close to it as available detail will permit. Each print in succession should be adjusted until no break up of the grid plane along the principal point base line occurs. The prints for use in this stereoscope should preferably be made rather light in tone, as the thin black lines on the grid plates will then show up much clearer against the prints, and the "break-up" will be more readily observed.

The transfer of points from one point to another is carried out without difficulty if the prints are of good quality, and possess a variety of detail. The identification of such points is checked by inspection of the adjacent image points and by viewing the prints in fusion under a stereoscope. Where difficulty is experienced in identification of corresponding points, the stereoscopic method suggested by Captain Martin Hotine, Research Officer, Air Survey Committee, of the War Office, England, may be employed. This method involves the use of a suitable stereoscope and two small markers. Each marker consists of a small cross printed on thin transparent celluloid and formed by two fine black lines one inch in length or thereabouts crossing each other perpendicularly. The two photographs forming the pair which contain the point are adjusted under the stereoscope until fusion of the overlap area is obtained. One marker is placed over the point to be transferred with the intersection of the lines directly over the point and the lines forming the cross approximately at 45 degrees to the direction of the principal point base. The second marker is placed on the other print of the pair so that it fuses with the first and is then adjusted until the fused spatial cross appears to lie in contact with the ground and with the lines forming it crossing each other in the same plane. When in this position the intersection point is pricked through to the print and marks the location desired. Where difficulty is experienced in using the cross marker for the transferring of points, this may be caused by the quality of the print or of the cross itself. The relative strength of the cross and ground must harmonize. In general, it is best to use the finest possible lines forming the cross that can be seen clearly and in harmony with the landscape. With a little practice with prints of good quality, and a suitable cross marker, any person with a fair stereoscopic sense can readily effect the transfer of points by this method.

In addition to marking on each print the principal point bases, and accentuating thereon the selected image points and control features, difference of scale between photograph and plot necessitate the drawing of short radial lines extending one-half inch or more on either side of the two image points corre-

sponding to those selected opposite the principal point of the previous photograph used in extending the strip structure. The photograph markings required for the strip structure thus resemble Fig. 24, in which the arrow represents the direction in which the strip is being plotted and the circles around the selected image points are drawn free hand in coloured wax pencil.

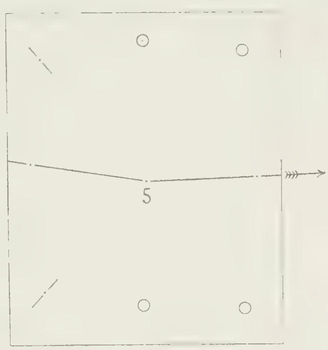


FIG. 24

Upon the completion of the strip plot structure the detail of the photographs required to be shown on the map is "marked up" on the prints either with white ink or coloured pencil. For transferring this information to the strip plot, each photograph is in turn placed under it and oriented by means of the principal point and adjoining principal point bases. If the country is level and the average scale of the photographs corresponds to that of the plot, much of the topography can be traced direct, but usually it is necessary in filling in between points fixed by radial intersections from two photographs, to distribute the difference by slightly shifting the tracing plot on the photograph.

Where the differences in scale of plot and photograph are large, it becomes necessary to fix on the plot, by intersection of radial directions from two photographs, a greater number of points to control the plotting, bearing in mind the final map scale as the governing factor in determining how far to go in the matter. Where contours have been added to the photographs, they may be transferred to the plot by noting the plotted positions of image points which lie on or near the contour and giving the same displacement to the contour as to such plotted image points.

After the strip plot has been completed, it is reduced to the scale of the projection sheet upon which the reduced plots of all strips are assembled. This reduction may be carried out either by photography, pantograph or other means. Photography involves the inking in of the strip plot, the making of glass negatives to the scale of the projection and the printing of contact prints therefrom on thin photographic paper. When the reduction is effected by pantograph, the reduced plot made in pencil on thin tracing paper is traced in position to the projection sheet by the use of transfer paper, where it is further adjusted, if necessary, and inked in. In either case to facilitate the reduction and control its direction, a straight line is drawn on the strip plot throughout its length, and measured.

Revision from Individual Photographs.—In cases where vertical aerial photographs have been taken over a previously mapped area, they may often be advantageously used for filling in or supplementing the information shown on the available map. For this purpose, the map location of the principal point of the photograph may be fixed by the radial directions to three control points such as section, or quarter-section corners, or other previously mapped features, in a manner similar to the graphical solution of the three point problem. Further points may then be fixed by intersections from the principal points of two photographs. If the photographs lack the overlap necessary for this purpose, plotting can frequently be extended, without introducing serious errors, over the central portion at least of any photograph by directions from the principal point and using for a scale $\frac{f}{H}$ that determined from a known line passing at its middle distance through or near the principal point. Assuming that the flying is carefully done and the tilts are small, the maximum displacement on the

photograph of image points resulting from tilt may be considered radial and to be equal to $\frac{d^2\,\theta}{f}$ (see page 35) where d is the distance on the prints of the image point from the principal point, f is the focal length of the lens in inches and θ is the circular measure of the tilt. Similarly the displacement of a hill feature may be considered radial from the principal point and amounting to $\frac{h}{H} \times d$ (see page 38) where h represents the height of the hill above the datum plane or mean level of the area shown in the photograph, and H is the height of the lens above this plane as determined from the scale $\frac{f}{H}$ obtained as stated.

MAPPING FROM VERTICAL AERIAL PHOTOGRAPHS

Vertical aerial photographs for mapping purposes may, of course, be taken from different heights and with cameras of different focal lengths, depending upon the purposes to be served. For the two-mile and one-mile mapping purposes of the Topographical Survey they have, up to the present, regularly been taken from an altitude of 10,000 feet, using a camera with an eight-inch focal length lens. In taking these photographs, the flights are arranged along straight parallel lines, spaced about one mile apart, an overlap in the direction of flight of more than fifty per cent being provided for between successive photographs. A print from each negative on 8″ by 10″ semi-matte double-weight paper is supplied to the office.

The first step upon receipt of the photographs is the preparation of an index diagram to show the relation of all photographs to one another and to points of the ground control (see Fig. 25). The best available map is used for this purpose, one on a scale of four miles to an inch generally being preferred. The photographs are examined and the position of the plate centre or principal point of every tenth picture is plotted as accurately as possible on this map and indicated by a small circle, together with the number of the negative. These circles are then joined by coloured ink lines, a separate colour being used to designate different rolls. The number of the roll is written along the line.

Flying in a straight line under certain conditions is not easy; frequently the flight lines are not parallel, so that gaps may occur, lines may be duplicated, etc. In such cases it may not be necessary to plot all photographs on hand.

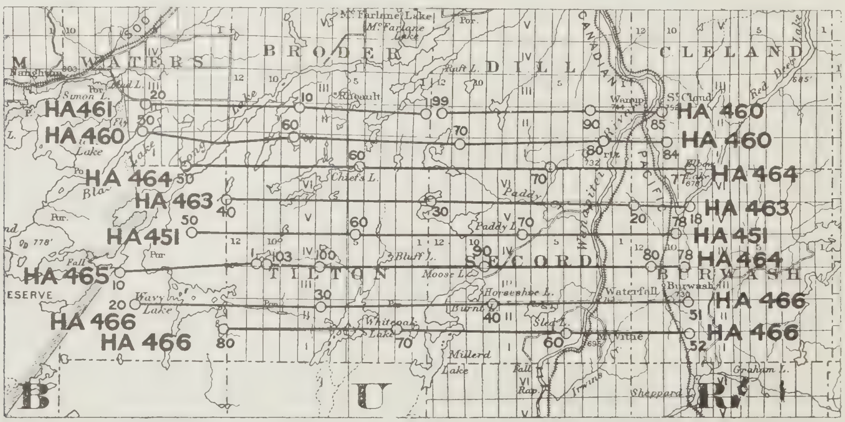


Fig. 25.—Index to Vertical Aerial Photographs.
In the actual indexes kept, separate colours are used to designate the different rolls.

Generally before the construction of the map is commenced, the area in question is divided into blocks with surveyed control lines as boundaries. Each block is then treated as a unit in very much the same manner as a plane table sheet, and for reference is designated by a letter. The flight lines which give full coverage are chosen and broken at the boundaries of each block. These are numbered as strips and indicated on a map which when completed becomes the "plotting index" (see Fig. 26). The photographs for the flight lines of each block are generally kept together in special boxes, for convenience in handling.

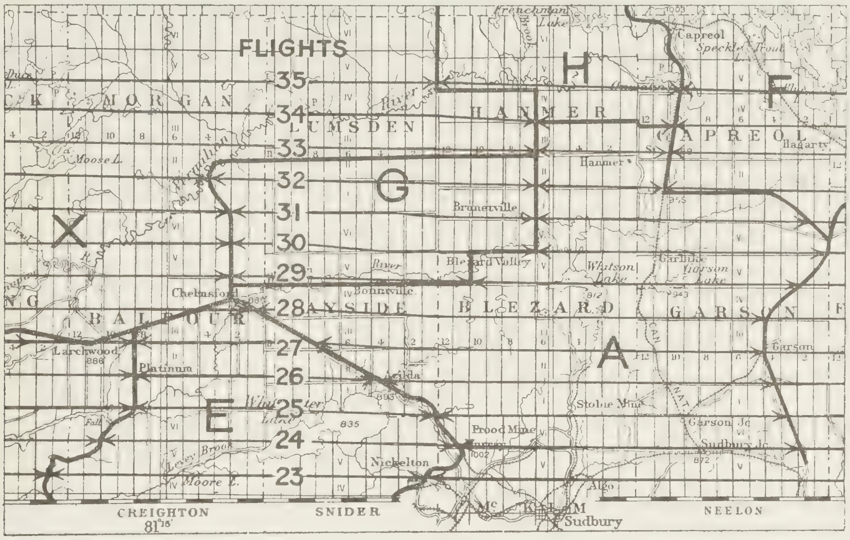


FIG. 26.—Plotting Index.
In the actual indexes kept, separate colours are used to designate the flight lines and the different block outlines.

The plotting index showing the blocks and flight lines can also be used to indicate the progress of the work, light washes in colours being used to indicate the stages or portions of stages as completed.

The radial intersection method of plotting used in the construction of the map is based on the assumption (as previously stated) that aerial photographs taken with the camera axis approximately vertical are angle true at the principal point. The principal point, being a function of the camera construction, does not vary with the unknown conditions of exposure and hence it is always available for use. Its position, as before noted, being usually etched as a cross on the focal plane glass plate against which the film carrying the sensitive emulsion is pressed during the exposure instant, it is directly recorded on each negative and on prints therefrom. The radial intersection method is particularly applicable to mapping areas of flattish or gently undulating country. The errors inherent in the underlying assumption become noticeable where the area to be mapped is one of considerable relief and the flying is of poor quality. The result is that it is necessary in the plotting of a strip of such photographs to obtain ground control at frequent intervals and thus avoid cumulative errors of appreciable magnitude.

The first step to be taken in connection with preparing the photographs for plotting by the radial intersection method is to mark up the common principal point bases or transfer to adjacent photographs the principal points P_1, P_2, P_3,

etc., as shown on Fig. 27. If an English-type precision stereoscope (see Fig. 22) is available it is always employed for marking the principal point bases in the stereoscopic method described on pages 45 to 48. If it is not available other methods must be used which, however, are less satisfactory. The principal points will fall on ground detail whose corresponding images will appear on the neighbouring photographs of the strip (provided the overlap exceeds fifty per cent).

A convenient notation to adopt is to designate the principal point in the centre of each photograph by the capital letter P with a suffix denoting the number of the photograph. Because of the overlap each photograph will show the principal points of the preceding and following photographs; these points are designated by the small letter p with a suffix denoting the photograph to which it refers. Thus on the fifth photograph the principal point is denoted by P_5 while the principal points of the fourth and sixth photographs respectively, will be denoted by p_4 and p_6.

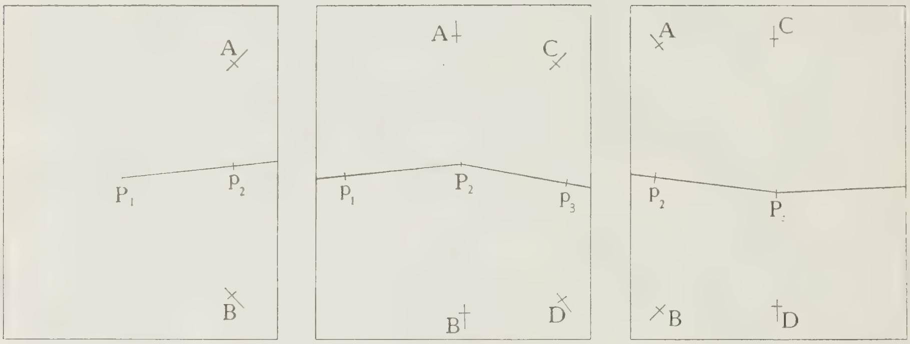


Fig. 27

The lines P_1p_2 and p_1P_2 are known as the "principal point bases" (see preceding chapter) and on the assumption that directions from the principal points are correct, will represent a common direction by which the photographs may be linked in pairs. The principal points are transferred to the neighbouring photographs only as a means of obtaining a common direction, as they are not otherwise used (this is explained more fully in the method of plotting by direction below). Should the overlap fall short of fifty per cent, or the place on which the principal point falls be devoid of detail, the common direction can still be found, for the principal point bases or common directions will pass through or miss the same features in the common overlap by the same amount, and by trial it is possible to locate the line which would join the principal points. Then, by joining the principal points by a very fine pencil line a good check is provided on the accuracy with which these points have been transferred.

In general, when transferring points it is well to have two fine needle prickers, one to serve as a guide and the other to mark the points after they are located.

The direct and most satisfactory method is to identify the point of detail on which a principal point falls, and to pick up and mark this same point on the two neighbouring pictures, then join these by fine pencil lines and check as above explained.

The transference of the principal point or secondary control points, to be described later, may also be carried out by means of the cross markers and stereoscope as referred to on page 48. If the principal point falls in water in close proximity to land so that the legs of the cross fall on land this method may still be employed. In certain cases the following method may also be used

for transferring principal points or secondary control points where these fall in water.

On the overlapped portion of the control draw two or more lines which intersect at the principal point and which pass through points at the water level, as for instance, points on the shore line. These points on the shore line are then identified and marked on the neighbouring photographs and are similarly joined. The intersection of these lines will be the position of the principal point. Fixing the principal point by measurement from neighbouring detail should not be attempted.

Where the principal point falls in water but the principal point base crosses an area showing detail, the direction of the principal point base is readily established by the method described on page 45. It is not necessary in the usual plotting work to know the actual location on this base of the transferred principal point as the secondary control points govern the scale of the strip plot.

The principal point bases, giving the common direction of the photographs, are carried throughout the strips.

If the principal point falls in open water where no detail along the principal point base is available it is necessary to break the strip plot and obtain control at such breaks or add the portion of the strips so broken on to an adjoining strip. This procedure is also necessary where secondary control points cannot be selected in water area.

To serve for controlling the uniform scale of a strip plot, secondary control points or points of detail A and B, Fig. 27, are next chosen in the small overlap common to the first three photographs, such that P_1p_2, p_2A and p_2B are all approximately equal, and such that Ap_2B is approximately perpendicular to the principal point base P_1p_2. It is essential that these conditions be observed as nearly as possible in order that the graphical intersections obtained during plotting will intersect at about 45° and give well-defined intersections. These points are then identified and pricked with a fine needle on all three photographs. Similarly, points C and D are then chosen on the second, third and fourth photographs and so on throughout the strip. In practice it is not necessary to adopt any method of lettering or numbering points.

The photographs will subsequently be "marked up" when interpretation is made. When the prints used for plotting are taken to the field for interpretation, it is then advisable to mark in violet ink principal point bases and short radial lines through the secondary control points.

As illustrated in Fig. 28, the principal point base is drawn from the principal point right across the overlap to which it refers. This facilitates orientation of the print during plotting.

The radial lines to the minor control points are drawn about one inch long so as to project half an inch on either side of the point. The point itself is indicated by a short cross line. A circle is generally drawn around the principal point.

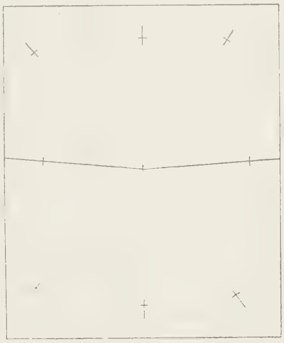


Fig. 28

The inking of these lines and points completes the preparation of the photographs for plotting in strip form by the radial intersection method. In the plotting a scale is assumed as determined from a line on a certain photograph, this scale being carried on the strip plot through consecutive photographs. The idea in selecting the photograph to define the scale is to reduce as much as possible the work of transferring detail from photograph to plot. Except when some few photographs show a very large amount of detail this is generally effected by selecting a photograph taken at an average height above ground. When the strip plot extends from ground control to ground control the value of our assumed scale becomes known.

The strip plot is made on long strips of very transparent tracing linen. These strips are conveniently obtained by cutting (with a saw) a 36-inch roll into three equal parts before unrolling, thus obtaining three rolls each a little over twelve inches wide.

Before commencing the plotting proper, a principal point traverse is first traced from the photographs on tracing paper. This serves to give the general direction of the flight line and its approximate length on the scale of the photograph, and is used for orienting the principal point base of the first photograph on the linen strip.

The photograph of the series which has been chosen to define the scale is placed under the tracing linen with its principal point base oriented as above explained and held firmly in place. Call this photograph the first photograph and designate its principal point P_1 (refer to Fig. 27). The positions of the points P_1 and A are carefully marked on the tracing and the radial direction P_1B traced. By accepting the distance P_1A we have defined the scale of the plot and for the succeeding photographs of the strip plotting must be confined entirely to directions if no further assumptions as to scale are to be made.

The first photograph is now removed and the second photograph placed under the tracing so that the line p_1P_2 on the photograph coincides with the direction P_1P_2 on the tracing; the actual position of P_2 on the tracing is not yet known. To fix this position of P_2 the tracing is moved over the photograph always maintaining the same orientation—that is, the direction P_1P_2 on the tracing coinciding with the line p_1P_2 on the photograph—until the radial direction P_2A on the photograph passes through the position of the point A as already fixed on the tracing. The tracing is then held firmly in place, the position of the principal point P_2 marked on the tracing by a short vertical line and the radial directions of B, C, D and of the next principal point base P_2p_3 traced (see Fig. 29). The position of the point B on the tracing has now been determined by the intersection of the radial directions P_1B and P_2B.

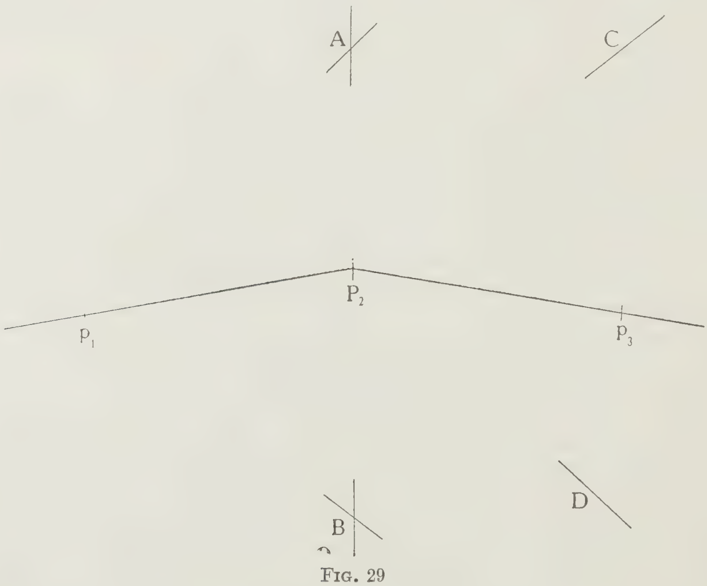


FIG. 29

The third photograph is next placed under the tracing, oriented along the principal point base and slid along this common direction until the radial direction P_3A on the photograph passes through the position of this point, as already plotted on the tracing. The radial direction to B should now pass

through the plotted position of B. If so, it provides a check on the plotting and the position of P_3 can be marked on the tracing, as also can the radial directions P_3C, P_3D, etc.

If, however, the radial direction to B does not pass through the plotted position it may indicate an error in plotting, probably a point incorrectly transferred or lack of care in plotting. If the plotting and transferring have been carefully and accurately done, the discrepancy must be due to a combination of tilt and hilly country. When the discrepancy is small the tracing should be readjusted over the photograph, always keeping it properly oriented by sliding it along the principal point base—until a mean position is obtained so that the directions P_3A and P_3B miss the plotted points A and B by the same amount in opposite directions. This mean position having been adopted, the principal point and radial directions are traced as described above. When the triangle of error is large the method of adjustment as given by Captain Martin Hotine in "Simple Methods of Surveying from Air Photographs" (Professional Paper No. 3 of the Air Survey Committee, The War Office, England, 1927) is sometimes used.

The fourth and succeeding photographs to complete the strip are added to the plot in exactly the same manner.

When plotting is commenced at the beginning or end of a flight, it will be seen that no check is available on the position and orientation of the second photograph, while the third and succeeding photographs are plotted from the two minor control points previously fixed. For this reason it is advisable to commence plotting so that no detail before the second overlap need be accepted.

In cases where the fore-and-aft overlap falls short of fifty per cent the direct method of transferring principal points becomes impossible, and, from the fact that there is no longer a small overlap common to three photographs, it will be found impossible to choose minor control points as a means of completing and checking the join between successive photographs in the strip. Under these conditions the radial line method of plotting cannot be applied without making further assumptions.

The principal point bases can be transferred as previously explained. It then remains to provide minor control points as a means of checking the orientation and fixing the succeeding principal point in distance. The following method by Captain Hotine is frequently used.

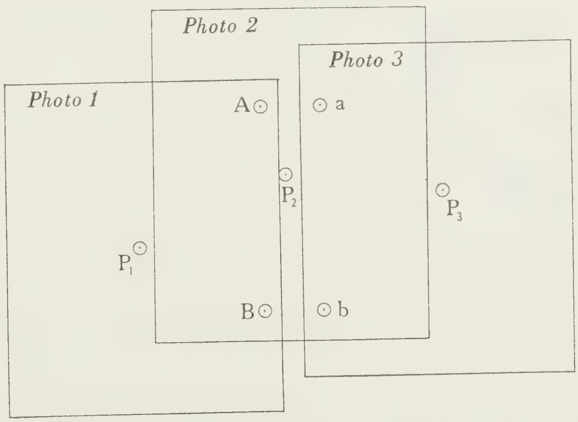


FIG. 30

Suppose that A and B on the central photograph of a set of three successive ones (Photo 2 of Fig. 30) are the last pair of minor control points which it has been possible to intersect in the usual manner. The succeeding photograph

(Photo 3 in figure) fails to overlap Photo 2 sufficiently for A and B to appear on it. While Photo 2 and Photo 3 are under stereoscopic examination, choose and mark substitute minor control points a and b which appear on both photographs. These points a and b should lie close to A and B and should, moreover, lie as nearly as possible at the same stereoscopic depth as A and B respectively. The points a and b have now to be transferred to the linen minor control plot. Photo 2 is placed in its correct position and orientation under the tracing with its principal point at P_2 (Fig. 31). A_1 is the plotted position of the point A as determined from Photos 1 and 2 while A and a are the photograph positions of the minor control and substitute minor control points as they now appear, (Fig. 31) on the photograph under the tracing. The position of a on the tracing is plotted by "pulling" a in towards P_2 in the ratio P_2A to P_2A_1. A construction for this latter operation—which in most cases can be performed by eye—is to join P_2a and $A\ a$ and to draw A_1a_1 parallel to Aa.

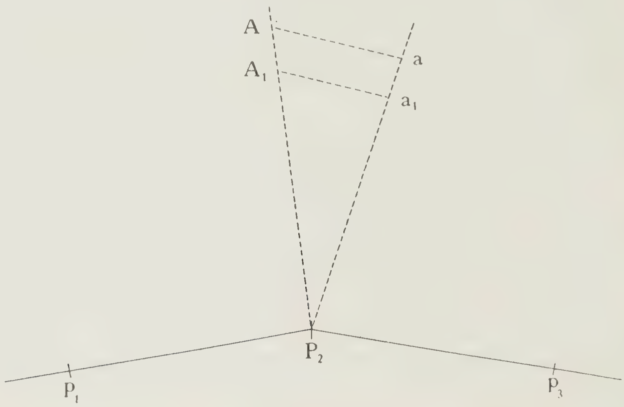


Fig. 31

The only further assumption made in the above procedure is that the local scale of the photograph is constant over the area between A and a, and this is quite reasonable provided A and a are not too far apart or at very different heights. Due attention will have been paid to these points in selecting A and a.

The succeeding principal point P_3 is then fixed and adjusted from a, b, and the principal point base in the normal manner.

If a second short overlap is to be tacked on to the plot, it is merely necessary to intersect two minor control points appearing on both Photo 2 and Photo 3 and to choose, in the manner outlined above, substitute minor control points which appear on Photo 3 and the succeeding photograph. No further variation in principle is involved.

On the photographs at each end of the strip a certain number of stations or positions occupied during the course of the control survey have been identified and marked thereon by pricking with a fine needle. These points of control should be transferred to neighbouring photographs and short radial lines drawn from the principal points so that they will be intersected and located on the linen control plot.

It is also necessary to locate and intersect auxiliary points on the common overlap of adjacent strips. These auxiliary points should be chosen at suitable intervals and will serve for comparing the plotting of adjacent strips and also for assembly purposes. When adjoining strips are compared the discrepancy should not exceed one per cent. After the strip is completed the principal points are made permanent by inking in with black ink and numbering every fifth. A triangle in black ink with a letter is used to indicate the auxiliary tie points

common to adjacent flight lines. Points on the control which have been identified in the field and which have been intersected are indicated by a small circle in red. Water colour should be used as it is opaque and will photograph better than coloured ink. When the flights are in an east and west direction the designation of the block, number of flight and photographs used, should be placed in the northwest corner of the strips. This facilitates the subsequent handling in that when the title is in the upper left-hand corner the strip is facing north. A similar procedure is followed when photographic flights are taken in other directions.

Interpretation of Photographs.—The interpretation of a photograph is a difficult matter. In general, features which form regular lines on aerial photographs are easily interpreted; of such are roads, railroads, trails, streams, shore lines, etc. The direction of flow of small streams with overhanging trees, houses, barns, swamps and other features partly concealed are difficult to clearly identify and much more satisfactory results are obtained if these are interpreted in the field. It should be borne in mind that many photographs have small blemishes and scratches, usually not prominent enough to be conspicuous, but which are liable to mar parts of the photograph enough to interfere with obtaining satisfactory results when making close examination; but blemishes and scratches are readily detected under the stereoscope. Shapes, and particularly heights, are most valuable in determining the character of objects. Every means which affords clear impressions of heights of objects should therefore be employed. These are convincing reasons why all areas to be mapped, or about which information of any kind is sought, should be covered with pairs of photographs which afford stereoscopic vision of the terrain. There are many types of stereoscopes which are used to examine aerial photographs. For interpretation purposes the simple reflecting pattern is most suitable. It has the advantage that no special mounting of photograph is required. Photographs are completely separated when being viewed and sketching can be carried thereon conveniently.

In the construction of the map sheets of the Topographical Survey, a mirror-type stereoscope (see Fig. 22 or 32) is made use of for the office interpretation of topographical features. Generally only surveys engineers with considerable experience as topographers are employed on this work. The method of procedure is to examine the portion of the photographs which afford stereoscopic vision and to outline all topographical features with white ink.

In general the order is as follows. The photograph to be inserted on the left-hand side of the stereoscope is the first picture of the strip. The outlines of all features to be mapped are then sketched on the photograph to the right. The one to the left is then removed and the photograph on which the sketching has been done is moved to the left side and the next adjacent photograph is inserted in its place and the sketching carried thereon. This is carried on until the topography has been interpreted over the entire strip.

When looking through the stereoscope after the second and third photographs have been inserted in place the topography which has been outlined in white on the second photograph is merely continued on the right picture and new features, if any occur, are added. In this way there is no duplication of inking features, also all topography which it is desired to show is continuous and complete, which makes it possible to employ junior help to transfer it to the strips.

In some cases, particularly where there is much cultural detail, it is necessary to resort to field interpretation of the topography. The field officer carries with him the vertical photographs and, by actual inspection upon the ground, identifies such features as buildings, churches, post offices, roads in their various classification, etc.

So far as the use of aerial photographs for contouring is concerned various methods to this end have been applied by the Topographical Survey, but no particular method has yet been submitted as standard practice. Hence it is not considered advisable to touch upon them in this bulletin, which may be revised at a later date.

Fig. 32.—Mirror-type Stereoscope

By use of the stereoscope the impression of relief is given to the common portion of a pair of overlapping photographs, thereby facilitating the study of the topographic detail. See also Fig. 22.

Transferring Data.—If the ground is level and the flying has been carried on at a constant elevation, if the photographs have been taken without tilt, and if the strips have been plotted at the scale of the photograph, it would only be necessary to trace on the strip from the photographs the details of the topography which are required for the final maps. However, even under the best of conditions there are frequent displacements, mainly due to differences in height, necessitating a certain amount of adjustment in transferring detail.

This adjustment is made on the general assumption that the direction of any point of detail from its corresponding principal point is correctly shown upon the photograph. In cases of large differences in elevation this would involve plotting by "point-by-point" intersections, or if preferred a frame work of intersections may be provided and the intervening detail equated. The points for this frame work of intersections should be chosen under the stereoscope so as to make certain that there are no considerable variations in heights within the area to be equated.

Usually, when the differences of heights are not too great, and consequently the adjustment small, the practice is to make this adjustment of topographical detail from photograph to linen strip by sight. This is accomplished by orienting the linen plot over the photograph and ascertaining the displacements of the minor control points. The points of detail are then connected proportionately

by shifting the linen plot over the photograph on the line joining the principal point and the point of detail in question. For differences in height, on a single photograph, of less than 500 feet and for a map which is to be published at a scale of two miles to an inch, this latter method has been found sufficiently accurate.

Inking in of these strip plots is necessary as they are subsequently reduced by photography as explained below. In general, when the interpretation is made in the office, black india ink is used. In cases when a topographical party in the field has made the interpretation which contains additional information not visible in the photographs, such as telephone lines, culverts, classification of roads, etc., the practice has been to use the regular colours and symbols as adopted for plane table sheets, water colours being used in place of inks on account of their better photographing qualities. These can be waterproofed by a solution if necessary.

Measuring Strip Plots for Reduction.—The operation of measuring strip plots for reduction is comparatively simple. Projection sheets are provided which show in position the control points which have been identified on the photographs and which have subsequently been intersected on the strip plots. It remains to measure the distance between corresponding points on the strip plot and on the projection and the division of the former by the latter gives the reduction factor.

Measurements are made with an electrum straight edge 150 cms. long and graduated to centimeters and millimeters.

Reductions are made photographically on glass plates and prints furnished on thin vandyke paper. The strip plots which extend from ground control to ground control, are generally of a greater length than can be photographed on one negative, with the apparatus available at the Topographical Survey, two and sometimes three negatives being required to cover the entire strip. To ensure accuracy in reassembling these parts after reduction and also for the convenience of the photographer, a straight line is drawn at the lower edge along the entire length of the strip plot. This line is then divided into the required number of parts as will be necessary in photographing. Small lines drawn at right angles across this line indicate the positions at which the strip is to be broken. The reduction factor, distance between these vertical lines, and the required distance between these vertical lines after photographic reduction are indicated on each strip.

Assembly of Reduction of Strip Plots to Projection Sheets.—Reductions on vandyke paper are usually correct to scale within half a millimeter for a length of twenty inches and this discrepancy can usually be corrected before assembly by ironing out the strip if too large and dampening if short.

The assembly of the reduced vandyke strip to the projection is made by superimposing the fixed terminal points of the strip, which are points of the ground control, on the corresponding positions of these points as plotted on the projection sheet, making minor adjustment to the adjacent strips as required and then sticking down with rubber cement. Frequently it is found that the topographical detail along the edge of a strip does not exactly agree in position with the topographical detail of the adjacent strip. This is rarely due to an error in the plotting of the strip itself, but generally results from the method adopted of transferring the detail from the photograph to the linen strip. The topographical detail covering the portion along the centre line of a strip can ordinarily be more accurately plotted than that along the edges and should not be displaced when assembling—except when an error has been proved—minor adjustments being made to the edges as necessary.

After all the strips for a projection have been laid, the edges are touched up and the sheet photographed and reduced to the intermediate mapping scale.

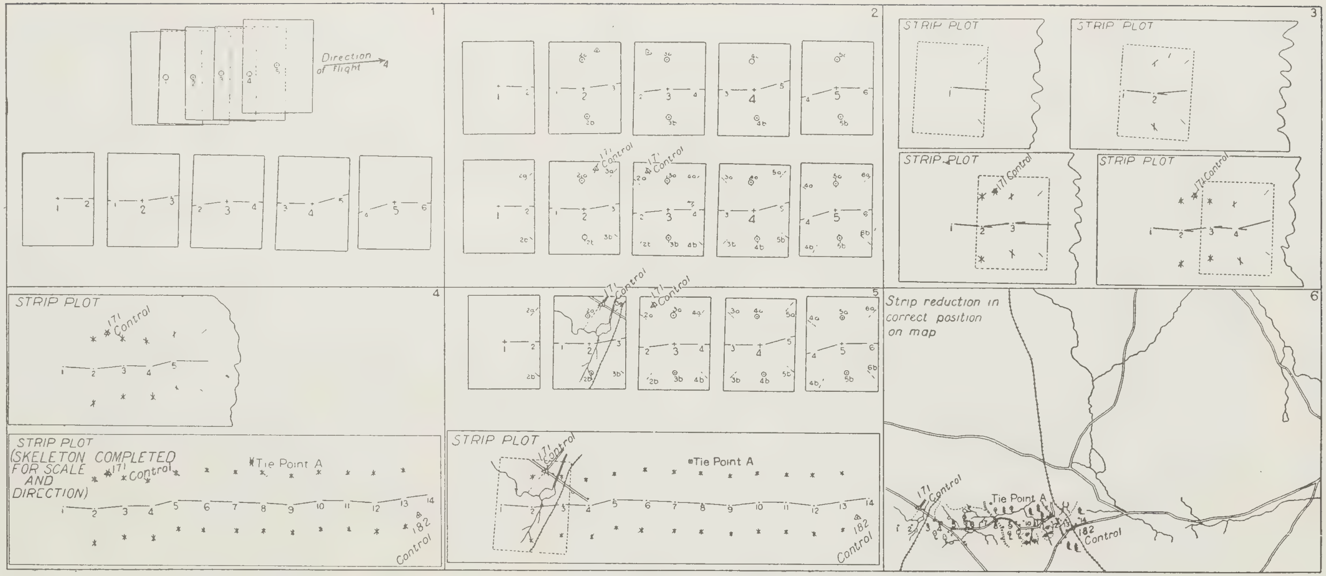


Fig. 33.—Radial Intersection Method of Plotting Vertical Photographs.

1. Five consecutive vertical photographs with overlaps of over 50 per cent shown (above) superimposed and with principal points 1 to 5 marked thereon, and (below) with principal point bases marked.

2. The five consecutive vertical photographs with (above) selected minor control points opposite each principal point also "marked up" and (below) with these points shown "marked up" and with short radial lines drawn therethrough on the overlaps common to adjacent prints, and also through control point "171", thus making them ready for the strip structure plot.

3. First, second, third and fourth photograph of the flight being placed in turn under the transparent tracing linen or xylonite on which the strip plot is made.

4. Skeleton strip plot structure showing (above) points traced from first five photographs, and (below) those across the strip to the intersection of control point 182, both control points 171 and 182 being fixed by intersection.

5. Mapping detail (above) being "marked up" for transfer to the strip plot tracing, and (below) shown so transferred. In so transferring, each photograph is placed in turn under the tracing to agree with the radial directions of image points from each of two consecutive principal points.

6. Strip reduction in correct position on the projection sheet on which has been previously plotted the main control data for the assembly of these reductions.

As the principal points of the photographs have been inked in on the strip plots, they appear on the reductions and in assembling are allowed to remain in their correct positions, thus providing an accurate index of the photographs on the intermediate mapping scale.

The final checking of topography is done on this intermediate mapping scale before turning over the sheet to the draughting division for redrawing.

Summarizing the above method we first of all index the photographs as they are received, then select and break up flight lines at points of control. The photographs then being in proper order, the plotting is carried on by stages as follows:—

(1) Transferring principal points and minor control points.
(2) Plotting skeleton strips.
(3) Interpretation of topography.
(4) Completing the strip plot by transferring topography.
(5) Measuring strip plot for reduction.
(6) Assembly of reduced strip plots to projection.

A good class of junior or clerical help may be employed on stages 1, 2 and 4, but in order to achieve the best results only experienced and well qualified men should undertake the other stages. A diagrammatic representation of the various steps of plotting by the radial intersection method is given in Fig. 33.

GROUND CONTROL FOR AERIAL MAPPING

The remarks which follow in this section deal with the special features to be considered in supplying control for aerial mapping. The methods followed being the same as in general use for all mapping work, the subject is covered only in a broad and general way.

An oblique photograph taken from the air represents a bird's-eye view of the terrain within the field of view of the camera and, if a series of straight-ahead views were plotted by "grids" as explained in a previous chapter, we would have a strip plot, subject to certain errors, from the beginning to the end of that flight. If, however, we wish to embody this information into a map, the errors of the strip plot must be reduced, so far as may be reasonably possible, and also the definite position into which the strip plot fits in the resulting map must be determined.

It is here that the necessity for ground surveys or "ground control", as it is called, comes in. Such ground control is essential before practical use may be made of the photographs for mapping purposes. It may further be stated as a general axiom that, provided the flying and the resulting photographs are up to the desired standards, the accuracy of a map produced by aerial methods varies directly with the amount of ground control supplied.

Control for Oblique Photographs.—Oblique aerial photographs have been used in the Topographical Survey mostly for the production of maps of the National Topographic series to the four-mile scale, each map sheet covering one degree in latitude and two degrees in longitude. When it has been decided to map a particular area by oblique aerial photographs, the first step is to procure a copy of the best available previous map of the district and lay down a scheme of control for the aerial work. As oblique photography is mostly used in mapping unsettled areas where there are few, if any, roads and where communication may be either largely or entirely by water routes, it is evident that at the very outset the location of these control lines is limited. Seldom, if ever, can ground surveys be made which will furnish the ideal control for the aerial mapping; it always resolves itself into a case of doing the best possible with what is available.

As the lines of flight are for practical reasons limited to east and west lines, and as control mileage is reduced to a minimum when it intersects the lines of

flight at approximately right angles, it follows that the control for oblique mapping should run in a general north and south direction, where at all possible. An ideal condition would be to have north and south control lines on the east and west margins of the sheet, and three others dividing the sheet roughly into quarters. Such a condition is, of course, very seldom obtainable and, in most cases, the control lines for the east and west margins of the sheet will fall either inside or outside that sheet; if inside, some other means must be found for controlling the photographs for the margin and, if outside, the flight lines must be carried beyond the sheet to the control.

After the general scheme of control has been decided upon, the lines of flight are laid out and planned to suit the control. In aerial methods, although on account of the urgency for the publication of a particular map sheet it may not always be expedient to have the flying done in one season and the ground control done the following season, this practice should be followed whenever possible. With the photographic prints in the hands of the ground surveyor engaged in the laying down of the ground traverse, positive identification either of the station or, in lieu thereof, of unmistakable natural features tied into the traverse, may be made on the pictures. It may, in fact, be stated that this is the only certain way of ensuring correct identification.

As previously stated, the oblique method has the striking characteristic that, under proper conditions, an azimuth line can be laid down very accurately on the photographs, being independent of any changes of altitude in either the aeroplane or the terrain. The conditions required would include a sufficient diversity of natural features, a sufficiently straight line path of the aeroplane, the pointing of the camera directly along the path, and first class photographs from a photographic standpoint.

Given these conditions, and with the further assumption that the deviation of the plumb line from the geodetic normal does not vary over the area of the four-mile sheet to be mapped, it would be possible to control such a sheet satisfactorily and at very low cost, as shown on Fig. 34. In this figure *ABCD* represents a four-mile map sheet extending over 1° in latitude and 2° in longitude

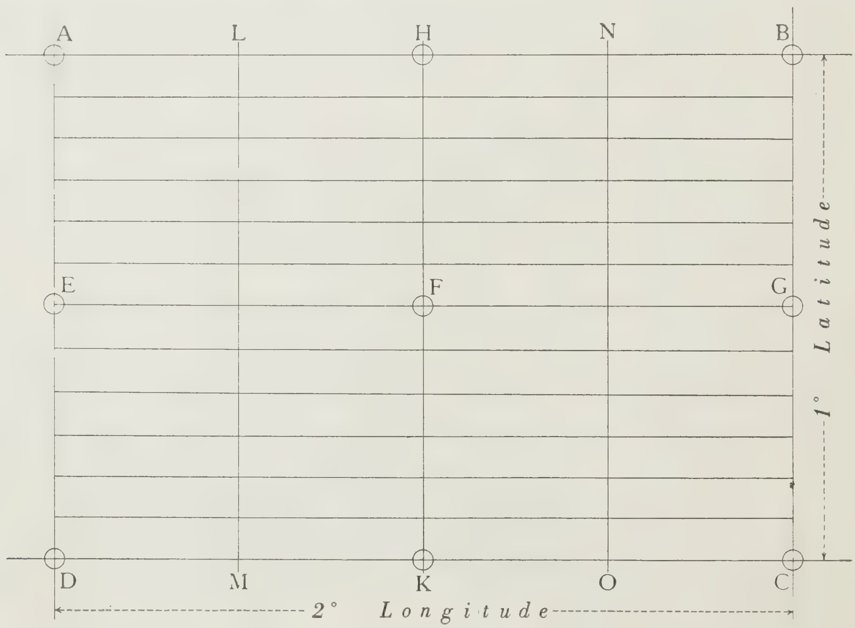


Fig. 34

and covering an area of approximately 6,000 square miles. *DA*, *ML*, *KH*, *ON* and *CB* are azimuth lines run from south to north and the astronomical latitude and longitude of points at the intersections of the azimuth lines with the flight lines at *A*, *H*, *B*, *G*, *F*, *E*, *D*, *K* and *C* have been determined by observation.

It will be noted that the four corners of the map sheet are definitely tied down and that each of the azimuth lines *AB*, *CD*, *DA*, *KH* and *CB* is controlled both at its ends and midway, or at distances not exceeding forty or forty-five miles, the flight lines being further controlled by two intermediate south to north azimuth lines, *ML* and *ON*.

If stronger control is desired, astronomical observations for latitude and longitude could be taken at the intersections of flight lines at *M*, *L*, *N* and *O*.

Such a scheme of control should be quite satisfactory with the conditions stated, and in the areas being mapped by oblique photography (low relief and plenty of water) there should be no insurmountable difficulties in placing by plane an observing party at or near the desired points. Against this, however, it may be stated at once that the conditions are seldom as stated; the flying and the photographs are rarely uniformly sufficiently good to warrant this method, and there is always doubt as to the assumption of constancy of deviation of the plumb line. In practice, therefore, it is only adopted as a last resource and then only in part.

Fig. 35 is a diagram of the control actually laid down for one of the four mile map sheets. *ABCD* represents the sheet to be mapped, *E*, *F*, *G* and *H* astronomical observations for latitude and longitude, fixing the starting points of stadia traverses and at the same time controlling the railway right-of-way plots, and *K*, *L* and *M* further latitude and longitude observations, controlling

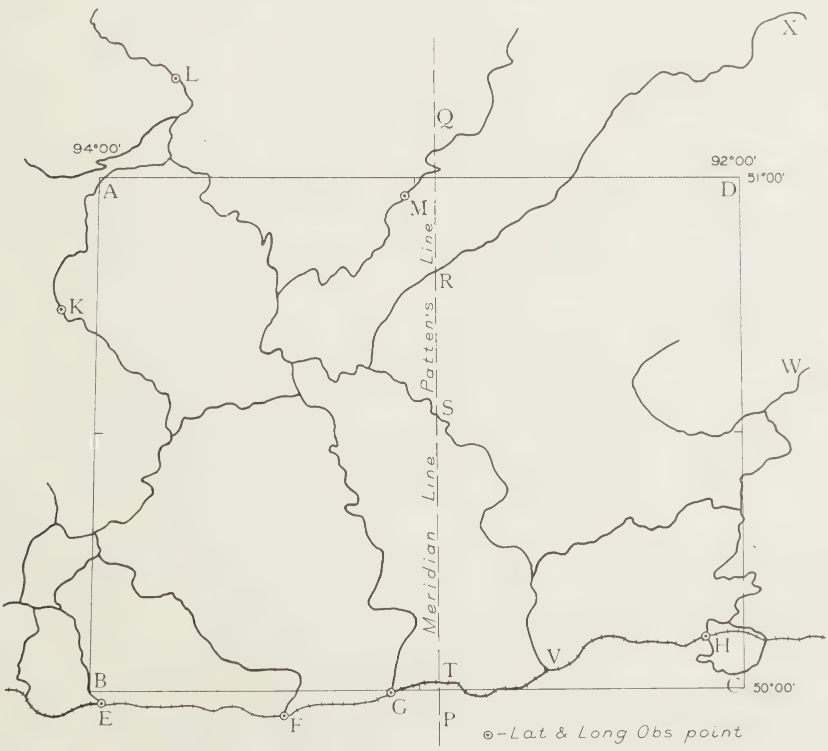


FIG. 35

traverses; *PQ* is a meridian survey of the Ontario land survey system which, while not evident in the photographs, was useful in controlling the stadia traverses *S* and *R*; a chain traverse was made on the railway from *G* to *H*, and the starting point *V* of the stadia traverse in this way determined. It will be noted that the northeast part of the sheet is apparently lacking in control; in point of fact, however, the traverses *X* and *W* join up on the adjoining sheet and form a block or closed circuit. As the distance from *R* to *W*, however, was considered excessive an azimuth line was flown down *CD*, connecting also to the traverse line *RX*, which furnished satisfactory control.

Control for Vertical Photographs.—Vertical photographs are generally used for mapping to larger scales than the oblique photographs, or for mapping country that cannot, on account of the roughness of terrain, be covered by the other. They are also, of course, used for the making of mosaic maps. In connection with control for vertical photographs for the production of line maps, although these are not subject to some of the limitations of the oblique photographs they lack the same facility for carrying along an "azimuth line" for considerable distances. Consequently the vertical photographic method requires much more ground control than the oblique method.

The section, township and base lines laid down under the Dominion lands surveys system furnish ideal control for vertical photography for all the settled portions of the western provinces. Whether the sheet be flown in an east and west or in a north and south direction, township outlines will intersect the flight lines at intervals of every six miles, and section lines every mile for east and west lines and (for the most part) every two miles for north and south lines, so that the roads and fence lines will serve as excellent control for the sheet.

An example of the type of control used on vertical work for a two-mile sheet, where lines laid down under the Dominion lands surveys system are not available is shown in Fig. 36. The traverses are chained, the standard of accuracy laid down being that the closings must be one in five thousand or better. It is always an advantage to have a number of geodetic stations distributed over the sheet, as it not only strengthens the work but simplifies the adjustments and gives an added confidence to the results. In this case there was an entire lack of geodetic control, the datum for the work being a single geodetic station carried across the adjoining sheet to the south by a series of closed circuits, the final closing on further geodetic stations not being obtained until the control had been laid down over a considerable portion of the contiguous sheet to the north.

For average country, control for vertical photographs is desired at intervals of eight or ten miles along the flight lines. If possible, the interval distance between should not exceed twelve miles, though in numerous cases it is found impracticable to keep within these limits. In the case in point the country had been subdivided many years previously and, while the township outlines did not show in the pictures, they were tied in to the control and points on the lines identified, so that considerable supplementary control was in this way furnished. As a result in no case did the distance between control along flight lines exceed twelve miles and in general it may be said that the control for this sheet is excellent. The northwest corner of the sheet is controlled by the intersection of two control flights, *HA* and *DA*. The control flight *HA* intersects the lines of ground control at *H* and *G*; and similarly the control flight *DA* intersects the lines of ground control at *Q*, *P*, *N*, *M* and *L*. The northeast corner of the sheet is similarly controlled by the intersection of control lines *AD* and *CE*.

Where at all feasible, chained control should be used as ground control for the vertical photographs. On some of the map sheets, however, it is not practicable, on account of prohibitive cost, to supply all the control required by this

method and triangulation, stadia traverses, astronomic fixes or other methods have to be resorted to. In such cases, the ground control is naturally not of the same strength as with chained traverses.

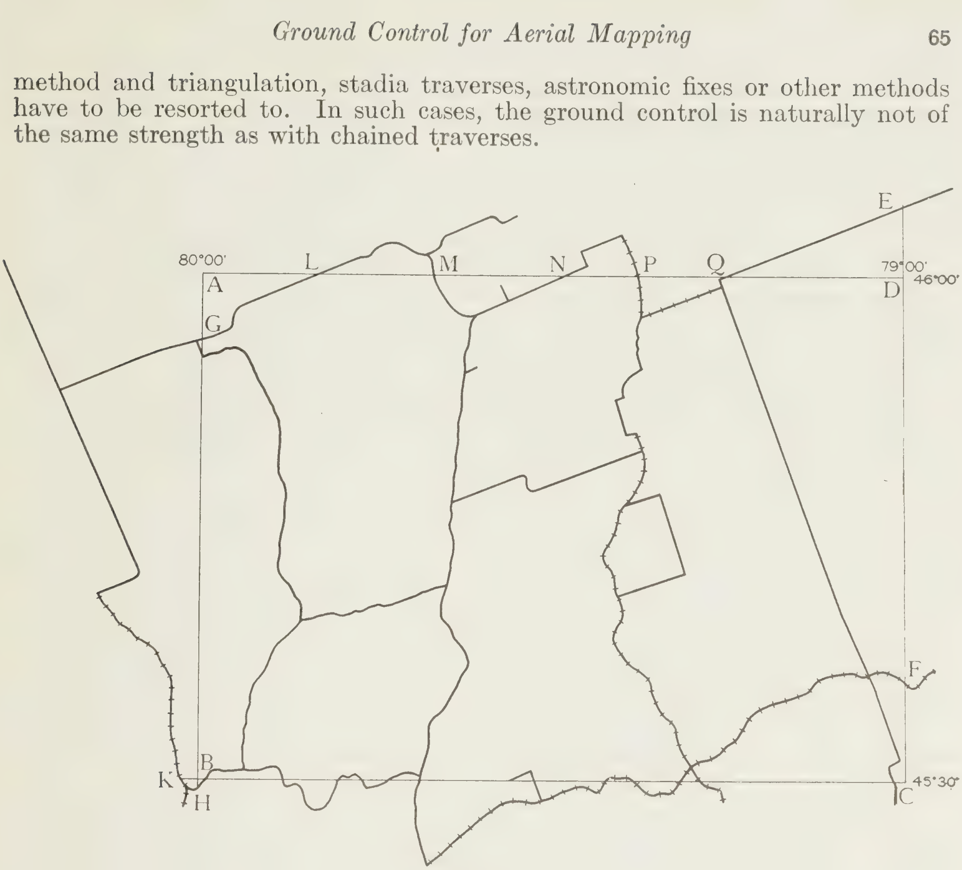


Fig. 36

In a general way the remarks regarding the control required for the preparation of line maps from vertical aerial photographs apply also to the preparation of mosaic maps (referred to in the next section of this bulletin). These are usually constructed on scales slightly larger than the average scale of the original photographs. Sufficient glass negatives are then prepared by photography to cover the mosaic, which permit the preparation of photographic prints on various scales to suit particular requirements.

As the demand for mosaic maps is largely due to the amount of detail shown thereon, their value, especially for engineering and town planning purposes, is increased when this information is shown on a working scale. For this reason the mosaic may be defined as a large scale aerial photographic map. As such, it is apparent that the amount of control necessary will vary with the accuracy required for the completed mosaic, the latter being limited by the range of the relief existing in the area.

In unsettled territory where great accuracy is not essential, the control points along the different lines of flight should be approximately six miles apart for photographs obtained on a scale of 1,000 feet to the inch and, as heretofore mentioned, these control points should be identified on the photographs by the surveyor on the ground wherever possible.

An increase in the scale of the photographs involves an increase in the number of photographs to cover an area and this in turn necessitates a corresponding increase in the control.

In the preparation of mosaic maps of settled areas more control is required and this is often available from the plans of local surveys. Such plans usually provide sufficient control points to enable the negatives to be rectified for tilt as well as scale, thus preventing an accumulation of errors that would result from control separated at greater distances.

Aerial Photographs as a Guide to Ground Surveyor.—The surveyor on the ground, whether laying down control for oblique or for vertical photographs, should have with him prints of the aerial photographs. As his traverse lines cross the lines of flight, his traverse stations should be identified on the prints by pricking through with a fine needle point their definite positions. If the station cannot be positively identified on the print, it should not be attempted, and some clear, unmistakable feature in the vicinity shown in the photographs should be tied in by the traverse and pricked through instead. In order that there may be no mistake in the identification, at least two points are required, and three are desirable, across every flight.

In the case of oblique photographs, the identification points must be marked on photographs on which they appear well in the foreground. In order that scale may be obtained as well as identification, when the traverse crosses more or less at right angles to the photographs, the identification points should be as far apart as it is possible for them to be while still appearing in the same view.

Many details, such as houses, streams, etc., are sometimes hidden in the photographs and should be marked; the nature and size of the timber, the width, depth and direction of flow of the streams and whether they are continuous or intermittent, should be noted. Muskegs should be shown; where rock is exposed, its nature should be stated; and descriptive notes of the fish, game and general character of the country are desired.

Oblique photographs have up to the present been used only for four-mile map sheets and vertical photographs for two-mile map sheets, for one-mile map sheets, and for mosaic maps, though interest and probable developments in sections where the terrain is too rough and broken for oblique photography, will necessitate the mapping of areas, where a four-mile map is sufficient for practical requirements, by vertical photography. In such cases, in order to reduce both ground control and flying costs, it will probably be necessary to either increase the altitude at which the photographs are taken, use wider angled lenses at the same altitude, or adopt a combination of both. In this way a widening of the area covered by one photograph will be effected and the amount of ground control necessary reduced.

Oblique photographs for the production of four-mile map sheets are plotted on a scale of one mile to an inch. Vertical photographs for the production of two-mile map sheets are plotted to the scale of the pictures and the resulting strip plots reduced to a scale of one-half mile to an inch. Accordingly, the projection sheets showing the ground control are plotted on a scale of one mile to an inch for oblique photographs and one-half mile to an inch for vertical photographs. A heavy map bond paper seasoned eight to ten months is used. With obliques, as the reduction to the published map is four times and as the ground control is in nearly all cases of stadia accuracy, the distortion of the paper is not of an order to require special consideration and single sheets are used. But in the case of verticals the situation is somewhat different, the reduction for one-mile map sheets is only twice and the control is of a much higher order of accuracy, so that double sheets are used, cross mounted; that is to say, the paper is mounted with the grain of one sheet at right angles to that of the other—the effect being to make the expansion and contraction of the paper more uniform over the whole sheet.

MOSAIC MAPPING

What is usually referred to as a mosaic or aerial photographic map is one built up by joining together prints of individual near-vertical-axis aerial photographs or parts thereof in such manner as to have the topographical features appear continuous at the joins and to present a comprehensive view of the entire area.

Before commencing such an assembly, an index map showing the locations of the individual views covering the area is made for the following purposes:—

(1) To ascertain the existence of gap areas;
(2) To determine the amount of forward overlap present in the views comprising the separate photographic lines of flight;
(3) To study the amount and location of the ground control available for the proper assembly of the photographs;
(4) To examine the quality of the photographs and list the negative numbers of those selected for the assembly;
(5) To arrange the photographs in groups so as to be convenient for the subsequent plotting and detailed measurements.

To make a mosaic assembly it is evident that the photographs or parts thereof used for the purpose must, so far as possible, be brought to a common scale. If reduced prints can as conveniently be made as enlarged prints, any scale can be adopted for the assembly. In this case a scale which approximately averages the various scales of the contact prints from the different negatives would serve. If enlarged prints can more readily be produced by the available equipment, then it is usual to adopt for the scale of the mosaic assembly, a scale slightly larger than that shown by the largest scale photograph of the group.

All the control information is next plotted to the scale of the assembly, determined as below, on a sheet of heavy paper, on which the prints are later to be actually laid down. To counteract any tendency to change of scale in the paper resulting from the application to it of the liquid adhesive employed in mounting the photographs, and to ensure that the plane of the mosaic assembly is maintained flat during photography, the projection sheet is mounted by using rubber cement as the adhesive, on heavy composition board. This composition board is a stiff smooth-surface board 3/8″ thick, obtainable in sheets up to 6 by 12 feet in dimensions. After the prints have been assembled on the projection sheet and the assembly photographed, the sheet may then be removed from the card-board base for filing, leaving it available for the next assembly. Recent experiments have shown that if the surface of the board is waxed prior to the projection sheet being mounted, the latter may be more easily removed later.

Scale.—If the altitude H of the camera above the ground is known at the time of exposure, as well as the principal distance or focal length f of the camera lens (corrected for film and paper contraction) then the scale of the photograph, as before noted, is represented by the fraction $\frac{f}{H}$. The value for f is a laboratory determination, while H is deduced from barometric readings obtained with an altimeter designed for aerial photography. Both of these measurements are usually recorded on the first picture of a photographic roll.

It is apparent that variations in the elevation of the ground, which are not always readily obtained, will necessitate corrections to the recorded altimeter readings for H used in the scale expression. On this account this expression is used chiefly to quickly ascertain the approximate scale of the photographs. It is usual, however, to determine the scale of a photograph by comparing the distance measured on the photograph between two image points such as a and b with the distance measured on the ground between their corresponding object

points A and B, or with the distance measured on the projection or map of known scale between the plotted positions of A and B. Thus, if Xp represents the distance between the plotted positions of a and b measured on the photograph and Xm represents the distance between the plotted positions of A and B on the projection map and Xg represents the distance between A and B measured on the ground, the scale of the photograph equals

$$\frac{Xp}{Xg} = \frac{Xp}{Xm}\left(\frac{Xm}{Xg}\right)$$

$$= \frac{Xp}{Xm} \text{ (map scale).}$$

That is, the enlargement of the photograph necessary to have the image points a and b coincide with the corresponding plotted positions on the projection map is $\frac{Xm}{Xp}$. This factor must be increased by approximately one-half of one per cent to allow for the contraction of the printing paper resulting from its development. In selecting image points a and b for the determination of scale it is desirable that these points be situated on the photograph equally distant and on diametrically opposite sides of the principal point, as in this position their separation is not affected by tilt. Furthermore, if possible, the mean level of the selected points should conform to the average level of the area shown in the photograph.

The effect of tilt and relief are indicated in a photograph by displacements radial from the principal point and the combined maximum effect of such distortions in a photograph is avoided by rejecting, so far as possible, in the assembly and in the selected control points, the marginal parts of the photograph. This is possible if the photographs possess considerable forward and side overlap. Aerial photographs taken for mapping purposes, as previously noted, are required to have an overlap in the line of flight of over 50 per cent, and a similar side overlap between photographs taken on adjoining flights is desirable in photographs intended for a mosaic assembly. The control points necessary for determining the enlargement factors of individual photographs are made available in three ways:—

(1) The amount of ground control available in the area included in one photograph as plotted on the projection sheet for use in the assembly may be such as to allow for a selection of suitable scale points.

(2) If the photographs of a strip or portion thereof extending between control points plotted on the projection sheet possess the required 50 per cent overlap or more, a radial strip plot can be constructed and either the secondary control points required for the extension of the plot can be selected so as to be suitable for scale measurements or additional scale points can be intersected in the plot. The radial strip plot structure, including the additional scale points, can by use of the pantograph be laid down on the projection sheet and the required enlargement factors of the individual photographs determined as described heretofore.

In the absence of ground control points, the strips of photographs are plotted by the radial intersection method, and by intersecting points common to adjoining strips the radial strip structure of preferably a central strip is made to control the scale of adjoining strip plots. Provided barometric or altimeter heights of the camera at exposure and of the two scale points in the photograph are known, then the scale of the projection or assembly map can e determined, from the expression previously given, viz.:

$$\text{map scale} = \left(\frac{f}{H}\right)\left(\frac{Xm}{Xp}\right)$$

Where the letters f, H, Xm and Xp denote the quantities previously stated and the enlargement factors are then determined in the usual way.

(3) If the photographs obtained along a flight between ground control points whose positions have been plotted on the assembly projection lack sufficient forward overlap to enable the usual strip structure to be plotted as referred to in (2) above, then a plot of the principal point bases or lines joining the principal points of consecutive overlapping photographs is carried out to the scale of the respective photographs, and the plot is enlarged so that it fits on the terminal control points as plotted in position on the projection, to which the plot is transferred. The enlargement factor assigned to each individual photograph comprising such flight is the enlargement factor given to the plot to make it fit the projection, that is, the aeroplane is assumed to have maintained a uniform altitude above the ground when such views were taken.

The direction of adjoining principal point bases is marked on each photograph by reference to the image points in the common overlap in a manner similar to that used in radial intersection plotting as hereafter described. A common tie point on the overlap common to two adjacent views, about midway on such overlap and on or near the principal point base is identified and "marked up" on each pair of photographs to serve in fixing the length of each principal point base. The plot of the principal point bases is then carried out on tracing linen by superimposing the linen over each photograph in the order taken on the flight, beginning at the terminal photograph containing the control point and tracing therefrom the direction of the forward principal point base, and the locations of the principal point, control point and tie point at or near the principal point base.

The tracing is then superimposed on the next photograph so that the direction of the respective principal point base and tie point as marked on the tracing agrees with the corresponding direction and image of the tie point on the photograph and the position of the next principal point, principal point base and tie point is then drawn on the tracing and the operation repeated until the other terminal control is reached.

The English-type precision Stereoscope (see Fig. 22) is employed for establishing on the prints the direction of the principal point base as described on pages 45 to 48. The marginal portions only of the principal point base line are scratched on the prints by a fine needle. If this instrument is not available, a strip of stiff transparent celluloid about 1/20″ thick, 1″ wide and 14″ long, on which is etched a fine straight line, is employed. On this line near each terminal a pair of holes are carefully drilled about $3\frac{1}{2}''$ apart, just large enough to hold a No. 11 needle.

Fig. 37 illustrates the celluloid strip superimposed over a pair of prints with the terminal holes A and B of the strip directly over the principal points

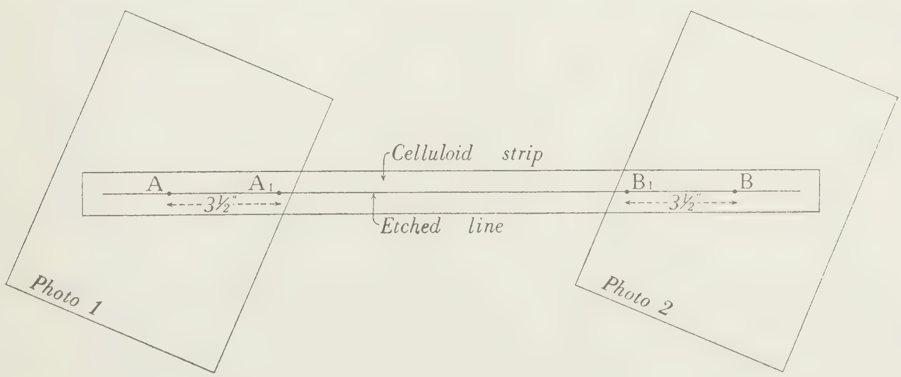


Fig. 37

of the photos in the manner in which it is used. A_1 and B_1 represent the central holes. The etched line is on the underside of the celluloid so as to be in actual contact with the photographs. A No. 11 needle is inserted at A and B piercing the prints at their principal points, the prints being separated sufficiently to allow for their rotation about these points. By trial the photographs are rotated until a position is found in which the image points along the line AA_1 on the overlap in the left-hand photograph are identical with the image points along the line BB_1 in the overlap on the right-hand photograph, and this orientation is marked by piercing each print with a needle inserted through holes A_1 and B_1. The celluloid is removed, and a fine line is drawn on each photograph from its principal point through the pierced hole near the edge of the print to mark the position of the principal point base.

Prints for the Assembly.—Prints for the actual assembly are made on singleweight, glossy bromide paper. The shrinkage of this paper is 6/10 of one per cent. As previously mentioned, this shrinkage must be considered in making the prints to the enlargement factors obtained. In addition, it is sometimes necessary also to take into account the change in dimensions of the film negative, which tends to shrink uniformly with the passage of time. This shrinkage in some negatives exceeds one per cent.

To facilitate the work of the photographer in producing an enlarged print to definite dimensions, use is made of the marginal rectangle which is etched on the glass plate in the focal register of the camera employed and which thus appears in each negative and in prints therefrom. By measuring the long side of this rectangle on the photographs used in determining the enlargement factor, and applying to this measurement the enlargement factor for the particular photograph, together with a further enlargement of 6/10 of one per cent for shrinkage allowance, a line is drawn on a sheet of paper to the length so determined, for each negative, and each line is marked with the negative number of the photograph with which it is to be used.

The photographer then sets his camera to enlarge the original negative until the long side of the rectangle as projected on the board is of the length shown on his paper and makes the bromide print at this camera setting. As all prints for the assembly are required to match in tone, the photographer is provided also with an index map showing the relative positions of the photographs so that tone comparisons can be readily made between adjoining prints.

When the corrected prints for the assembly are obtained, the principal point bases or lines joining the centres of consecutive overlapping photographs are indicated near their margins usually by comparing them with the previously marked prints. As the principal point positions are plotted on the assembly projection sheet, the assembly is carried out by superimposing respective principal points and aligning the principal points as marked on the photographs with their respective positions on the projection and fixing them in this position by the adhesive—known commercially as "arabol"—which has but slight effect on the scaled dimensions of the paper. Where the join of one photograph to another is made, the print is torn to a feather edge and carefully pasted down. Skill and good judgment are necessary in this phase of the work in order to obtain a satisfactory result.

When the assembly has been completed, some retouching is usually necessary, especially over the water areas, to correct any differences of tone in adjoining prints. This is accomplished with the aid of an air brush with a selected pigment. The names of all topographical features are then added, also the title, north point, border, graphical scale, etc. The assembly is then photographed and a glass negative made. If it is a large mosaic, several negatives may be necessary in order to completely cover it. These are carefully examined, retouched where necessary, recorded and preserved. They form a permanent record of each mosiac assembly and photographic prints may be had from them on any reasonable scale desired.

ELABORATING BASE MAP INFORMATION FROM AERIAL PHOTOGRAPHS

In addition to their use in the preparation of line and mosaic maps, aerial photographs may be used also to elaborate certain of the basic information appearing thereon. This information may relate to the mapping of timber, the utilization of water-power, the location of rock outcrops, and so on. The aerial photograph presenting as it does a picture of the earth's surface at the time it was taken, is rich in a great deal of detail which is ordinarily not made use of in the preparation of the line or base map, but which may be separately studied or added to the base map as required.

In the active development of the northern areas of Canada, the prospector and the surveyor are usually first upon the ground. They are soon followed by the forest officer, the engineer, the geologist and others; each seeking information along his own line. Expert interpretation of the detail revealed by the photographs will supply much of this.

With timber resources ranking among the most important in Canada, knowledge of the location and extent of timbered areas is essential to their proper development. Toward the obtaining of this knowledge, in co-operation with the Dominion Forest Service of the Department of the Interior, special studies were a few years ago undertaken of the aerial photographs to determine to what extent they might be used in supplementing the work of the parties who were to cruise the timber on the ground. As a result of this investigation, maps which show the location and character of the timber on certain areas have been compiled. The methods employed in compiling these timber maps have changed from time to time. An outline of the first method used and of that at present followed will be given.

Mapping Timber Types from Oblique Aerial Photographs.—The first work of this nature commenced in 1927, when timber type maps, covering an area of some thirty thousand square miles adjacent to lake Winnipeg in the province of Manitoba were made from oblique aerial photographs. The following information was to be added to the base map:—

(1) Timber.
(2) Boundaries of burns.
(3) Boundaries of muskegs.

A number of photographs of various areas in the tract to be typed were examined to determine if it would be possible to supply this information. In this connection such matters as the possibility of distinguishing the hardwoods from the softwoods and, should that be possible, of further subdividing the softwoods were taken into account.

It so happened that many of the photographs under examination had been taken at the season of the year when the leaves of the deciduous trees were changing colour. As a result there was no difficulty in differentiating between softwoods and hardwoods, the former appearing quite dark in colour in striking contrast to the grayish white tone of the latter. After careful study it was considered possible to divide the softwoods into three grades, as follows:—

Grade 1. To represent the most valuable stands.
Grade 2. To represent those stands of medium value.
Grade 3. To represent those stands of least value.

No difficulty was experienced in the selection of grade one softwoods. Stands of this type appeared very dark in colour on the photographs and a very good idea regarding the size of the timber was obtained at points where the outlines of the trees protruded over the shores of lakes and islands.

The division line between grades two and three presented difficulty, however, and it was not considered possible to determine this exactly from the

photographs alone. Nevertheless, a fairly accurate line could be established by making use of surveyors' field notes where surveyed lines happened to enter the area concerned, and afforded a means of comparison. In addition, an experienced interpreter using sharp photographs could place the division line with fair consistency by attention to grading of shades and by the exercise of judgment as to size of timber based upon his experience.

The interpretation was carried on by surveyors who were familiar with ground conditions pertaining to the areas to be mapped and who had become expert in the interpretation of photographic detail. Burns, rock barrens and muskegs were readily distinguished by them.

Numbers and the symbol as listed below were marked on the map to indicate the classes of timber. In this manner valuable space was reserved for the cruisers to enter any additional notes.

1. Good stands of softwood.
2. Medium stands of softwood.
3. Poor stands of softwood.
4. Burns, hardwoods.
5. Rock barren.

Muskeg.

Attention is directed to the fact that the work was undertaken for the purpose of providing working maps for the cruising parties and not with any idea of making a direct estimate of the merchantable softwood content.

Having these classes firmly fixed in mind the interpreters outlined the various classes as they appeared on the photographs. These division lines were then plotted by the use of grids, in the same manner as the boundaries of lakes and islands, as explained in a previous section "Mapping from Oblique Aerial Photographs" dealing with the plotting of the base map photography.

Scale of Photographs Used.—Contact prints measuring about seven inches vertically by nine inches horizontally were used, photographs themselves being taken from altitudes ranging from 4,300 to 5,200 feet.

In these oblique views, the typing in each case is carried from the foreground towards the background for a distance of about two and a half miles. In the mapping type of oblique view, the foreground of a photograph taken from an altitude of 5,000 feet above the ground, would represent a distance of one and a half miles on the ground, while the width of the background where plotting ceased, would represent four miles on the ground. Thus, the area typed from one photograph equals about 6·8 square miles.

Sometimes, of course, it was necessary to go into the background of certain photographs in order to connect type lines where overlap between adjacent flight lines was scanty.

The mapping of timber type boundaries from oblique photographs is illustrated in Figs. 38, 39, 40 and 41. Fig. 38 is an oblique mapping view showing a portion of Reindeer island in lake Winnipeg. Fig. 39 is the same view with main timber types outlined in white. Fig. 40 is Fig. 39 with mapping grid superimposed and Fig. 41 is the plot as developed outlining the main timber types.

Since the lines of the grid covering the plottable portion of the photograph are, when reduced to the ground surface, ten chains apart, it will be seen that it is readily possible to map quite small stands of timber in the immediate foreground of the photograph.

Information and Materials Supplied to Field Parties.—The field parties were supplied with prints of all the photographs covering the area to be

cruised, each cruiser carrying with him from day to day the views covering the immediate area travelled over. They were also supplied with maps of the region on scales of 40 and 160 chains to the inch. In order to save time in searching aimlessly through a large mass of photographs, the location of a sufficient number of them was indicated by arrows on the plans, the direction of the arrow in each case showing the direction in which the view was taken, the number of the photographic roll and the print number being also given.

On these maps the water routes were distinctly marked and consequently no guides were required.

Without them, also, it would have been necessary to run many miles of blazed control lines but, by accepting the topography as shown, a system of control was possible that had a degree of accuracy consistent with the character of the cruised lines.

The timber types, as shown on the maps, provided in advance much valuable information as to the character of the timber and its location, and thus enabled the chief of a party to plan his work to better advantage. Good locations for camps could be picked out in advance and cruise lines run so as to secure the maximum results within as short a time as possible.

Comparatively speaking, only a small portion of the areas examined supported timber of merchantable value, and as all the burned over areas, muskegs and rock barrens were outlined on the maps, the necessity of spending time and money to cruise these areas was obviated. It allowed the cruisers to concentrate their whole attention on the timbered areas, with a consequent increase in the value of their estimates of the stands of merchantable timber. This elimination of non-productive areas greatly reduced the cost of the field examination.

Fig. 38.—Oblique Mapping View of a portion of Reindeer Island in Lake Winnipeg

FIG. 39.—The Same View as Fig. 38 with Main Timber Types outlined in white

FIG. 40.—The Same View as Fig. 39 with Mapping Grid Superimposed

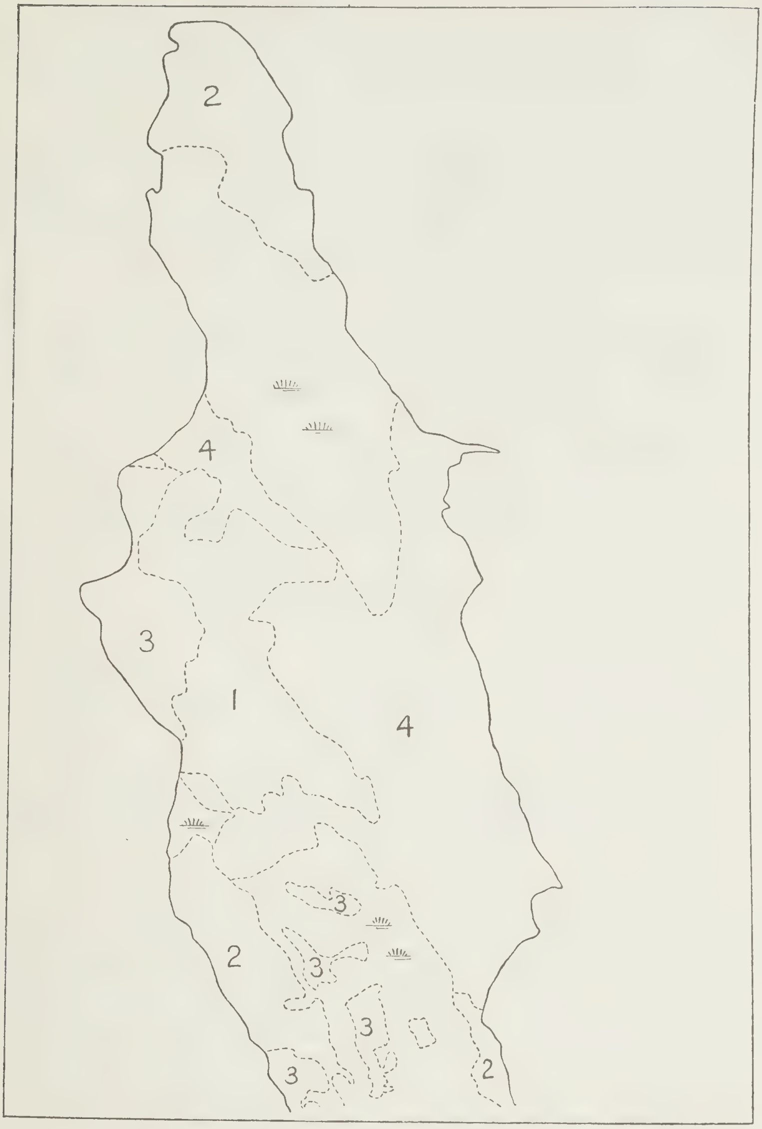


FIG. 41.—Plot as Developed outlining the Main Timber Types

The cruisers ordinarily, without the use of aerial photographs, would run their strips at intervals of forty to twenty chains, thus obtaining a one-and-a-quarter to two-and-a-half per cent cruise. In running these lines they obtained intimate information of the timber along and adjacent to them but, inasmuch as the compiler of their field notes had little knowledge of the timber on the areas between the lines, he had to join up the type lines of the cruising parties as well as he could. With the maps and aerial photographs at his disposal, however, this lack of knowledge vanished. Thus a better type line was established which added much to the accuracy of the estimate. The precision and detail of the base map topography was also a very important factor in obtaining the correct acreage of the various types. The areas enclosed by the boundaries of the various types were determined with the planimeter.

One outstanding result obtained from these type maps was that an estimate relative to the timber resources of the district cruised was obtained in a fraction of the time that would have been necessary under the old system. The feasibility, economy and efficiency of the service rendered was demonstrated beyond any doubt.

Information Shown on Later Type Maps.—As mentioned above, the method of describing types has changed from time to time. Latterly, it was decided that even better results would be obtained if the typing on the map was made to correspond with the system in use in the field. Hence in the latest work undertaken the following classes have been used:—

(A) Non-Forested Lands—	Symbol
(1) Open muskeg (less than 25% crown cover)	
(2) Rock	Rock
(3) Burn, not restocking (reproduction not visible)	Burn
(B) Forested Lands—	
(1) Merchantable Timber (2 cords per acre of trees 4 inches in diameter and over):	
(a) Softwood type (75% and over softwood)	So M
(b) Mixed type (less than 75% softwood or hardwood)	M M
(c) Hardwood type (75% and over hardwood)	Hd M
(2) Young growth:	
(a) Softwood type (as above)	So Y
(b) Mixed type (as above)	M Y
(c) Hardwood type (as above)	Hd Y
(3) Stagnated growth:	
Stands of slow growth which will not attain merchantable size in 30 years	

It will be seen that the classes listed as non-forested lands are practically the same as under the first system. Under forested lands, there are now really only two classes, one class consisting of the merchantable timber and the other of young timber.

Typing Timber from Vertical Aerial Photographs.—Vertical views taken along a flight line for mapping purposes regularly overlap, as before stated, from fifty to sixty per cent. By the aid of a stereoscope, an interpreter working with two overlapping views, can obtain a detailed knowledge as to the character of the surface and the relative height of objects. Burns, rock barrens and muskegs are consequently easily identified and the density of timber stands can be judged. The distinction between hardwoods and softwoods by colour also applies to vertical photographs taken when the leaves of the deciduous trees have changed colour, otherwise it is necessary to study the crown cover under the stereoscope, when the foliated tops of the hardwoods, in contrast to the pointed tops of the softwoods, will be the guide.

The boundaries of the types are outlined on the photographs with the aid of the stereoscope whereby density of stand and relative size of the trees is ascertained.

Contact prints are used, the detail visible depending upon the height at which the photographs were taken. For example, at 5,000 feet above the ground it is frequently possible to distinguish spruce from pine, whereas at 14,000 feet it becomes difficult to distinguish between softwoods and hardwoods. Photographs taken at 10,000 feet with a lens of eight-inch focal length have a scale of about 1,250 feet to the inch. The prints measure 7 inches by 9 inches, and cover space on the ground one mile by a mile and a half, or roughly one and a half square miles. This is a little less than one-quarter of the area which can be typed from an oblique photograph.

In the preparation of timber type maps from these vertical views, a tracing was first made of the base map, on which the location of the principal points of each photograph was also indicated. The type lines were then added by interpolating between the principal points of the photographs, as shown on the map, and the adjoining topographical features. If a greater degree of accuracy were required in locating the type boundaries, the distances between principal points of views as shown on the map could be used as a base and the type lines could be fixed by tracing them from the photographs, reducing the information by pantograph, and then tracing these lines onto the base map.

Where the surface is level, or fairly level, and where survey subdivision lines have been laid down on the ground, the plotting can be expedited by preparing a series of grids, the scale of the grid in each case corresponding with the scale of the photograph. This latter can be closely determined from the surveyed lines which appear on the photograph. The proper grid in each case being selected, the timber type lines can be plotted on cross-section paper prepared for the purpose. This information is then added to the base map by the use of transfer paper, the type lines being traced through to the map.

In typing timber either from oblique or vertical photographs it cannot be too strongly emphasized that it is necessary for the person who is to do the typing, or to direct it, to visit the district concerned in order to obtain a general idea regarding the distribution of types. This can best be accomplished by selecting views which are typical of the various classes and identifying them on the ground. In this manner a much more satisfactory type map will be produced than would otherwise be obtained.

Obtaining Other Information.—It has been demonstrated above how valuable the photographs have become as an aid to the rapid determination of the timber resources of a tract of land. Another use they serve is in connection with the discovery and development of water-powers. All important falls and rapids appear on the photographs, whether oblique or vertical, and these can be located on the base map. This is a simple process in comparison with the endless and strenuous task of locating them by canoe travel. To obtain the same amount of information over an area of six thousand square miles, which is approximately the area enclosed by one of the four-mile map sheets of the National Topographic series, would require many days of wearisome toil and endurance.

The aerial photograph, whether oblique or vertical, being a representation of the actual surface characteristics of the ground at the time it was taken may be used in specific cases for certain special purposes allied to that of obtaining topographical information. The photograph is, of course, subject to certain deficiencies and limitations and for this reason it may be said that in obtaining such information from it much valuable and sometimes even essential aid will be obtained by an examination of the ground. This ground examination, however, need not necessarily be very involved.

For instance, in the elaboration of water-power information for the purpose of studying potential possibilities of falls, rapids, etc., for their utilization and for the development of power, the aerial photographs form an invaluable aid. By their use and examination, particularly when adapted to stereoscopic study, the investigator is able to cover in a short space of time, in effect, areas which would take very much greater length of time and much more arduous effort to cover on the ground. Preliminary examination made on the photographs will enable the investigator to immediately set aside certain portions of the area under investigation and certain features of each, so that he may concentrate his efforts upon those which are more essential to the carrying out of the proposed project.

Thus, in the examination of an area for the laying out of a storage basin, for instance, he would be enabled in a very short space of time to determine at

what points the limits of the proposed basin would require artificial means to effect its construction. He would follow up the tributary ravines, coulees, etc., and would be able to determine the location of necessary dams, retaining walls, and so on, so that a visit to these actual locations would be sufficient to determine the feasibility of their construction and the nature of the construction required.

Other valuable information to be obtained from the photographs would be the location and nature of rock outcrops. This would be a matter of great interest to the geologist, prospector and others. They would, from an examination of the photographs, again particularly under the stereoscope, be able to determine upon what areas ground investigation would appear most promising and would thereby be able to eliminate much territory where rock exposures would seldom, if ever, be encountered.

Other uses might be cited such as, for instance, in the location of transmission lines, of railway rights of way, of highways, canals, and so on. It will thus be seen that aerial photographs, with their immense wealth of detail, are becoming more and more valuable for specific engineering purposes, in addition to their uses in the preparation of the topographic map. For all these purposes, however, the topographic map is a most valuable aid, particularly when used in conjunction with the photographs themselves.

INDEXING, RECORDING AND FILING AERIAL PHOTOGRAPHS

The centralization of the federal aerial survey work with the Topographic Survey, Department of the Interior, necessitated the establishment of an index and filing system therein. By this system, complete information is readily available regarding all aerial photographic work carried out, either directly or indirectly, by the Royal Canadian Air Force. The negatives of the photographs taken are retained by that organization, index prints of them being kept in the filing system of the Topographic Survey.

A small proportion of the aerial photographs, both oblique and vertical, in addition to any value they may have in connection with the work of mapping, may be used to serve other purposes as well, relating to the illustration of particular phases of development, or to what may be termed the presentation of scenic views. The index system is so arranged as to facilitate the locating of this information when required as well as all available information in connection with the regular mapping types of aerial photographs.

The index and filing system maintained at the Topographical Survey may be described under three main divisions, as follows:—

(1) The Index Card System, containing the essential information pertaining to each particular photograph.

(2) The Index Maps, indicating the locations of the aerial photographs.

(3) The Filing System itself, wherein a contact print of each available negative is filed in the respective container or containers allotted to the particular map sheet areas.

The Card Index System.—The aerial film employed with the aerial survey cameras at present in use is supplied in rolls, each of such length as to allow for 110 exposures, or thereabouts, the exposure area being approximately 7″ by 9″ in dimensions. When a roll has been entirely exposed it is forwarded for development to the Royal Canadian Air Force, Photographic Section, at Ottawa, and is accompanied by a report in duplicate, giving particulars that the camera operator can supply relative to the negatives contained therein. One copy of this report, with the proper roll number marked thereon, is immediately forwarded to the Aerial Photograph Index of the Topographical Survey. When the index prints of any roll of negatives are later supplied, information is thus readily available to serve for facilitating the preliminary handling of

the prints. When the roll is developed and before any contact prints are made therefrom, the negative roll number and the respective number of each exposure in such roll are marked on each film negative, each roll being numbered consecutively as received. In addition to these numbers the following information is marked on the first exposure of each roll:—

(a) The number of the roll;
(b) The date of exposure;
(c) The elevation;
(d) The camera and lens number;
(e) The operation number and line number of operation on which roll was taken.

In the card index one card is allotted to each roll. As soon as a roll of index prints is received a card is given the roll number as a heading, and a record is made on it of the following information:—

(a) Number of photographs contained in the particular roll;
(b) Date of exposure;
(c) Date of receipt;
(d) Number of copies received, photographic operation number, altitude, location;
(e) Information relative to camera and lens used, as obtained from the film report and camera calibration information available in the office;
(f) Disposal of photographs and cross reference to particular map index sheet showing index location of the photographs.

To insure against the loss of any of this information, it is also recorded in a book or register at the same time.

Index Maps.—The whole system of indexing, recording and filing is based on the location of the area shown in each aerial photograph. For indexing oblique aerial photographs the map sheets on the four-mile scale of the National Topographic series are used. If the particular four-mile sheet has not been issued, then a map is specially made to the required scale by enlarging or reducing the best available map, and with the proper boundaries to serve the purpose. On this map the locations of the oblique aerial photographic flights are marked, together with the corresponding negative roll numbers and sufficient of the exposure numbers of each roll to fix their map locations. To avoid congestion of index information on a sheet, the vertical aerial photographs are indexed apart from the obliques, but on the oblique index map any area covered by available vertical aerial photographs is indicated.

To serve as a temporary map index until the oblique photographic operation is completed, or until the close of the field season, the locations of the routes travelled by the aircraft when photographing, are indicated by lines drawn on a copy of the map accompanying the instructions for the photography. The roll numbers of the negatives obtained on those routes are marked on the lines as well as the locations and numbers of the first and last exposure, and a few intermediate exposures of each roll. Later, this information is added to the four-mile index sheet where inks of different colour are used for clearness in showing the locations and numbers of the different rolls. The negative numbers of all oblique aerial photographs indexed on any index map sheet are listed on the margin of the sheet in the same colour of ink as used in showing their map location. For indexing vertical aerial photographs, the one-mile scale map is employed with boundaries conforming to those of the one-mile map sheets of the National Topographic series. As soon as any photographs taken on a vertical aerial photographic operation are received, the routes on which they were obtained are marked by lines given the corresponding negative roll numbers, on a copy of the map accompanying the instructions for the operation. The

map locations of the principal points of the first, last, and a number of the intermediate exposures of each roll are fixed, numbered and marked by small circles. Locations of intervening exposures on the flight lines are determined by proportion. As an indication of the scale of the photographs the limits of the area covered by one exposure are drawn on the map. This temporary index map serves until the final index map is made.

In compiling maps from vertical aerial photographs by the radial intersection method, the map location of the principal point of each photograph used is fixed in the process. Prints, at the one-mile stage of these maps, which show by small circles the principal points of the photographs, are used for making the final index maps, each print covering the area of a one-mile map sheet of the National Topographic series. The route followed by the aircraft when exposing a particular roll is shown by joining in coloured ink the small circles, representing the consecutive exposures of such roll. The roll number and the number of the first, last and every fifth exposure, is marked in ink of the same colour as that of the route flown. The index map sheet is then marked with its proper number; the negative numbers of the photographs indexed thereon, are entered in their respective colour in the marginal list, and the outlines of the area covered in a few individual exposures are marked on the map.

Any additional vertical aerial photographs available covering any part of the map sheet area are added to the map index and listed thereon. Where a considerable number of large scale vertical aerial photographs, which cannot clearly be indexed thereon, cover a part of the area included on a one-mile vertical index map, they are indexed on a special large-scale map in a similar manner. The outlines of the area covered by such supplemental index map are marked on the one-mile index map and reference is made to it.

To facilitate the replacement of any index map sheet, if lost, a register is kept in which is entered the list of negative numbers of aerial photographs indexed upon each of them.

The Filing System.—Prints for filing are supplied on 9″ by 11″ double-weight, semi-matte paper, and the filing equipment for them consists of small steel boxes which are supported on steel shelving. Each box holds about two hundred photographs. Each section of shelving contains eight shelves and each shelf accommodates seven of the steel boxes. When the photographs are received for filing, and before they are entered on the index map sheet, they are temporarily placed in steel box containers headed with the photographic operation number on which the photographs were obtained, and marked with the roll and negative numbers of the photographs stored therein. As soon as any photographs have been indexed on any index map sheet, a steel filing box is marked with the number of such map sheet and the index photographs, as listed on the particular map in the container allotted to the map sheet area, are filed. The negative numbers of all the photographs stored in the box are marked on the card attached thereto. The steel boxes containing the vertical aerial views are grouped together and arranged according to their location, and those containing the oblique views are similarly grouped and placed on the shelving.

In addition to the regular index and filing system as above described—both of which are based entirely on location—a supplemental index and filing arrangement based on "subject" is being initiated. The supplemental subject index will apply to all aerial photographs of particular value for illustrating definite developments or resources and it will facilitate the examination of available views covering any particular subject.

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